Facts and Lessons of the Fukushima Nuclear Accident and Safety Improvement
-The Operator Viewpoints-

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DOE Nuclear Safety Workshop, @Bethesda, Maryland

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What I will present

1. How Tsunami struck Fukushima Sites
2. Tsunami Height Estimation
 -1 Facts
 -2 Lesson 1
  - Why we could not predict a large Tsunami
  - Why we could not prevent important electric facilities from flooding
  - How our organization can be more robust against natural hazards
3. How we responded in the Recovery Process ?
 -1 Facts
 -2 Lesson 2
  - Why we could not prevent our plants from core damage
  - How our organization can be more robust under emergency situation
4. Safety Improvement and Further Enhancement of Nuclear Safety

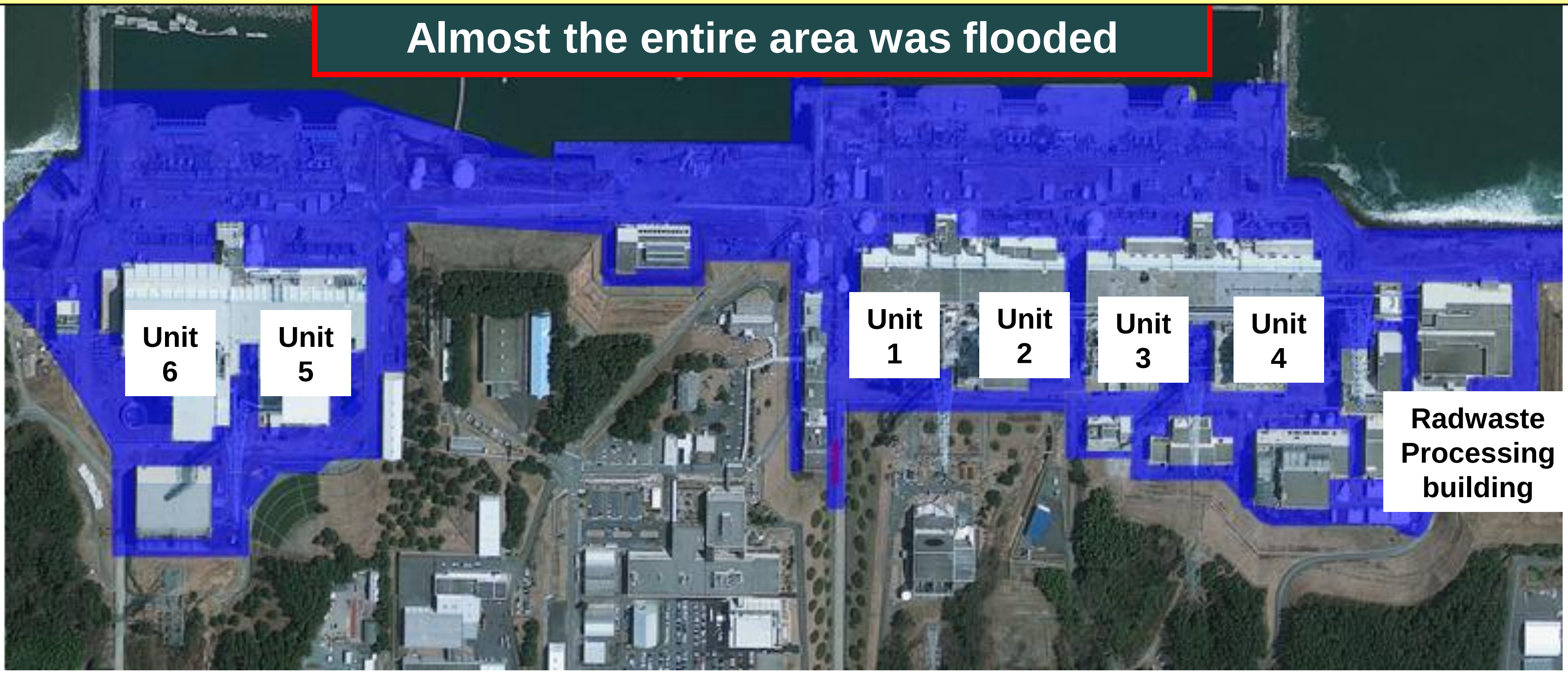
1. How Tsunami Struck Fukushima sites

Overview of Fukushima Daiichi NPS (1F) and Fukushima Daini NPS (2F)

Plant	Unit	In Operation Since	Plant Type	Power Output (MWe)	Main Contractor	Pre-earthquake Status
1F	1	1971.3	BWR-3	460	GE	Operating
	2	1974.7	BWR-4	784	GE/Toshiba	Operating
	3	1976.3	BWR-4	784	Toshiba	Operating
	4	1978.10	BWR-4	784	Hitachi	Shutdown for maintenance Full core offloaded to spent fuel pool
	5	1978.4	BWR-4	784	Toshiba	Shutdown for maintenance
	6	1979.10	BWR-5	1100	GE/Toshiba	Shutdown for maintenance
2F	1	1982.4	BWR-5	1100	Toshiba	Operating
	2	1984.2	BWR-5	1100	Hitachi	Operating
	3	1985.6	BWR-5	1100	Toshiba	Operating
	4	1987.8	BWR-5	1100	Toshiba	Operating

Impact of Earthquake/Tsunami at 1F

- Observed seismic acceleration was about the same as the design-basis.
  - ✓Plant responded as designed after earthquake.
  - ✓**No damage to safety-related equipment** due to earthquake confirmed to date.
- Tsunami severely flooded most of the major buildings located at 10-13m ASL.
  - ✓Estimated **tsunami height of 13m** much greater than **design-basis of 6.1 m.**
  - ✓Design-basis (6.1m) based on latest tsunami estimation methodology of Japan Society of Civil Engineers in 2002 which has been the standards for all NPP in Japan.



（C)GeoEye

Tsunami observed at Fukushima Daiichi (1F)
＜pictured from upland nearby Unit 5 ＞

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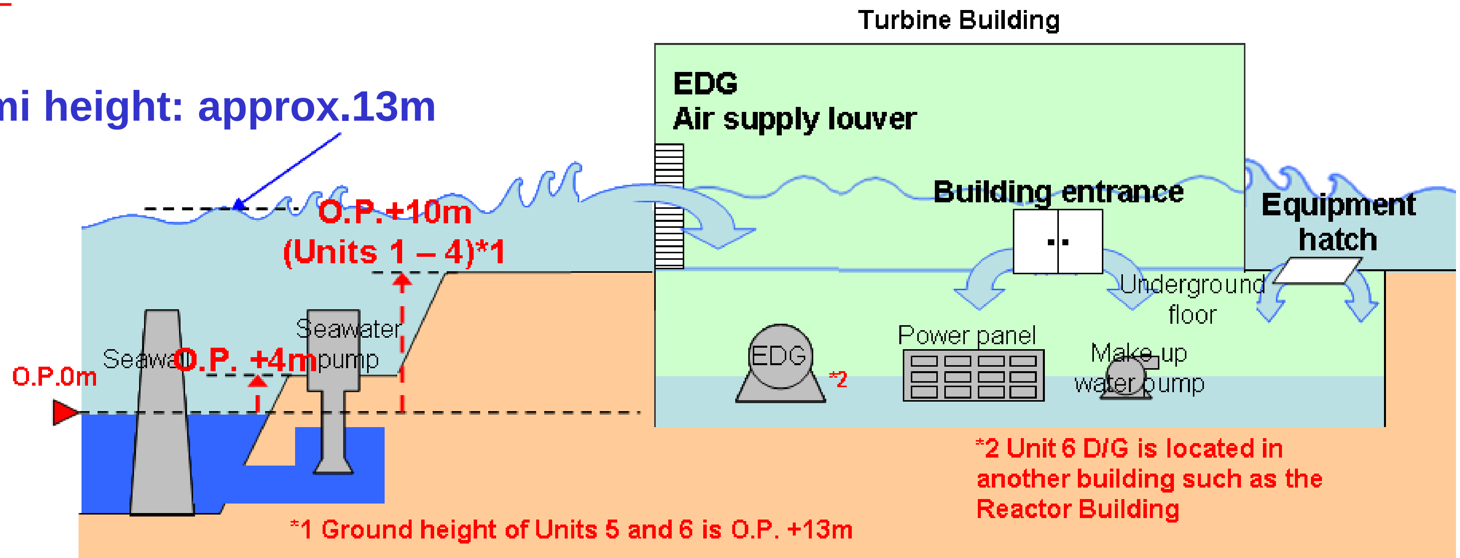
Tsunami Height 1F v.s. 2F

1F

Tsunami height: approx.13m

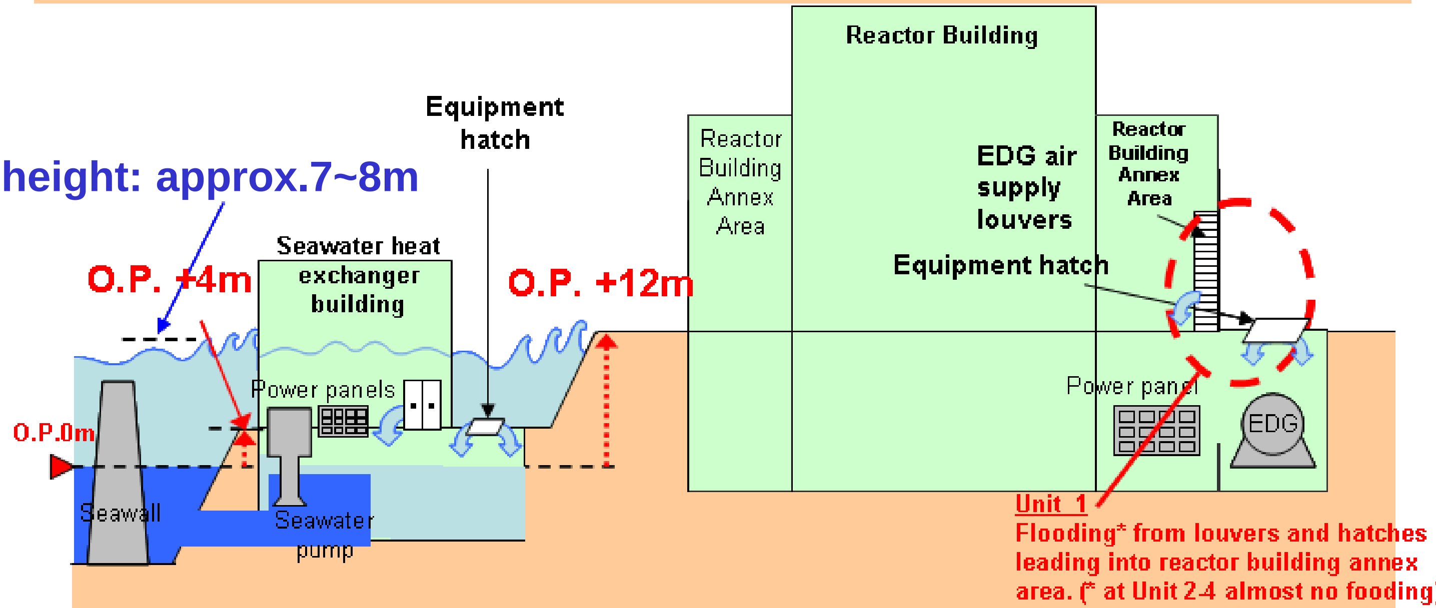
Design Basis Tsunami height: O.P+6.1 m



2F

Tsunami height: approx.7~8m

Design Basis Tsunami height: O.P+5.2 m



O.P. : Onahama Peil

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Integrity of Power Supply System After the Tsunami at 1F and 2F

1F:No off-site power available

Fukushima Daiichi

System	Use	Unit 1 Power panel	Can/can not be used	Unit 2 Power panel	Can/can not be used	Unit 3 Power panel	Can/can not be used	Unit 4 Power panel	Can/can not be used	Unit 5 Power panel	Can/can not be used	Unit 6 Power panel	Can/can not be used
DG		DG 1A	×	DG 2A	×	DG 3A	×	DG 4A	×	DG 5A(*2)	×	DG 6A	×(*2)
DG		DG 1B	×	DG 2B (air-cooled)	×(*1)	DG 3B	×	DG 4B (air-cooled)	×(*1)	DG 5B(*2)	×	DG 6B (air-cooled)	○
DG		–	–	–	–	–	–	–	–	–	–	HPCS DG	×(*2)
6.9KV M/C	Emergency use	M/C 1C	×	M/C 2C	×	M/C 3C	×	M/C 4C	×	M/C 5C	×	M/C 6C	○
6.9KV M/C	Emergency use	M/C 1D	×	M/C 2D	×	M/C 3D	×	M/C 4D	×	M/C 5D	×	M/C 6D	○
6.9KV M/C	Emergency use	–	–	M/C 2E	×	–	–	M/C 4E	×	–	–	HPCS DG M/C	○
6.9KV M/C	Regular use	M/C 1A	×	M/C 2A	×	M/C 3A	×	M/C 4A	×	M/C 5A	×	M/C 6A-1	×
6.9KV M/C	Regular use											M/C 6A-2	×
6.9KV M/C	Regular use	M/C 1B	×	M/C 2B	×	M/C 3B	×	M/C 4B	×	M/C 5B	×	M/C 6B-1	×
6.9KV M/C	Regular use											M/C 6B-2	×
6.9KV M/C	Regular use	M/C 1S	×	M/C 2SA	×	M/C 3SA	×	–		M/C 5SA-1	×	–	
6.9KV M/C	Regular use									M/C 5SA-2	×		
6.9KV M/C	Regular use			M/C 2SB	×	M/C 3SB	×			M/C 5SB-1	×		
6.9KV M/C	Regular use									M/C 5SB-2	×		
480V PC	Emergency use	P/C 1C	×	P/C 2C	○	P/C 3C	×	P/C 4C	○	P/C 5C	×	P/C 6C	○
480V PC	Emergency use	P/C 1D	×	P/C 2D	○	P/C 3D	×	P/C 4D	○	P/C 5D	×	P/C 6D	○
480V PC	Emergency use	–	–	P/C 2E	×	–	–	P/C 4E	×	–	–	P/C 6E	○
480V PC	Regular use	P/C 1A	×	P/C 2A	○	P/C 3A	×	P/C 4A	○	P/C 5A	×	P/C 6A-1	×
480V PC	Regular use			P/C 2A-1	×	–	–	–	–	P/C 5A-1	○	P/C 6A-2	×
480V PC	Regular use	P/C 1B	×	P/C 2B	○	P/C 3B	×	P/C 4B	○	P/C 5B	×	P/C 6B-1	×
480V PC	Regular use	–	–	–	–	–	–	–	–	P/C 5B-1	○	P/C 6B-2	×
480V PC	Regular use	P/C 1S	×	–	–	P/C 3SA	×	–	–	P/C 5SA	×	–	–
480V PC	Regular use	–	–	–	–	–	–	–	–	P/C 5SA-1	×	–	–
480V PC	Regular use	–	–	P/C 2SB	×	P/C 3SB	×	–	–	P/C 5SB	×	–	–
DC	125V DC	DC125V main bus panel A	×	DC125V P/C 2A	×	DC125V main bus panel 3A	○	DC125V main bus panel 4A	×	DC125V P/C 5A	○	DC125V DIST CENTER 6A	○
DC	125V DC	DC125V main bus panel B	×	DC125V P/C 2B	×	DC125V main bus panel 3B	○	DC125V main bus panel 4B	×	DC125V P/C 5B	○	DC125V DIST CENTER 6B	○
Sea water system	A	SW	×	RHRS A	×	RHRS A	×	RHRS A	×	RHRS A	×	RHRS A	×
Sea water system	B			RHRS B	×	RHRS B	×	RHRS B	×	RHRS B	×	RHRS B	×

2F:Off-site power survived

Fukushima Daini

System	Use	Unit 1 Power panel	Can/can not be used	Unit 2 Power panel	Can/can not be used	Unit 3 Power panel	Can/can not be used	Unit 4 Power panel	Can/can not be used
DG		DG 1A	×	DG 2A	×(*2)	DG 3A	×(*2)	DG 4A	×(*2)
DG		DG 1B	×	DG 2B	×(*2)	DG 3B	○	DG 4B	×(*2)
DG		DG 1H	×	DG 2H	×(*2)	DG 3H	○	DG 4H	○
6.9KV M/C	Emergency use	M/C 1C	×	M/C 2C	○	M/C 3C	○	M/C 4C	○
6.9KV M/C	Emergency use	M/C 1D	○	M/C 2D	○	M/C 3D	○	M/C 4D	○
6.9KV M/C	Emergency use	M/C 1H	×	M/C 2H	○	M/C 3H	○	M/C 4H	○
6.9KV M/C	Regular use	M/C 1A-1	○	M/C 2A-1	○	M/C 3A-1	○	M/C 4A-1	○
6.9KV M/C	Regular use	M/C 1A-2	○	M/C 2A-2	○	M/C 3A-2	○	M/C 4A-2	○
6.9KV M/C	Regular use	M/C 1B-1	○	M/C 2B-1	○	M/C 3B-1	○	M/C 4B-1	○
6.9KV M/C	Regular use	M/C 1B-2	○	M/C 2B-2	○	M/C 3B-2	○	M/C 4B-2	○
6.9KV M/C	Regular use	M/C 1SA-1	○	–		M/C 3SA-1	○	–	
6.9KV M/C	Regular use	M/C 1SA-2	○			M/C 3SA-2	○		
6.9KV M/C	Regular use	M/C 1SB-1	○			M/C 3SB-1	○		
6.9KV M/C	Regular use	M/C 1SB-2	○			M/C 3SB-2	○		
480V PC	Emergency use	P/C 1C-1	×	P/C 2C-1	○	P/C 3C-1	○	P/C 4C-1	○
480V PC	Emergency use	P/C 1C-2	×	P/C 2C-2	×	P/C 3C-2	×	P/C 4C-2	×
480V PC	Emergency use	P/C 1D-1	○	P/C 2D-1	○	P/C 3D-1	○	P/C 4D-1	○
480V PC	Regular use	P/C 1D-2	×	P/C 2D-2	×	P/C 3D-2	○	P/C 4D-2	×
480V PC	Regular use	P/C 1A-1	○	P/C 2A-1	○	P/C 3A-1	○	P/C 4A-1	○
480V PC	Regular use	P/C 1A-2	○	P/C 2A-2	○	P/C 3A-2	○	P/C 4A-2	○
480V PC	Regular use	P/C 1B-1	○	P/C 2B-1	○	P/C 3B-1	○	P/C 4B-1	○
480V PC	Regular use	P/C 1B-2	○	P/C 2B-2	○	P/C 3B-2	○	P/C 4B-2	○
480V PC	Regular use	P/C 1SA	○	–		P/C 3SA	○	–	
480V PC	Regular use	P/C 1SB	○			P/C 3SB	○		
DC	125V DC	DC125V main bus panel A	○	DC125V main bus panel A	○	DC125V main bus panel A	○	DC125V main bus panel A	○
DC	125V DC	DC125V main bus panel B	○	DC125V main bus panel B	○	DC125V main bus panel B	○	DC125V main bus panel B	○
Sea water system	A	RHRS A	×	RHRS A	×	RHRS A	×	RHRS A	×
Sea water system	B	RHRS B	×	RHRS B	×	RHRS B	○	RHRS B	×

Sea Water System

O: operable X: damaged

*1 functionality lost due to inundation of power panels *2 functionality lost due to the damage of sea water system

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2. Tsunami Height Estimation
- Facts

Historical Tsunami before March 11th, 2011

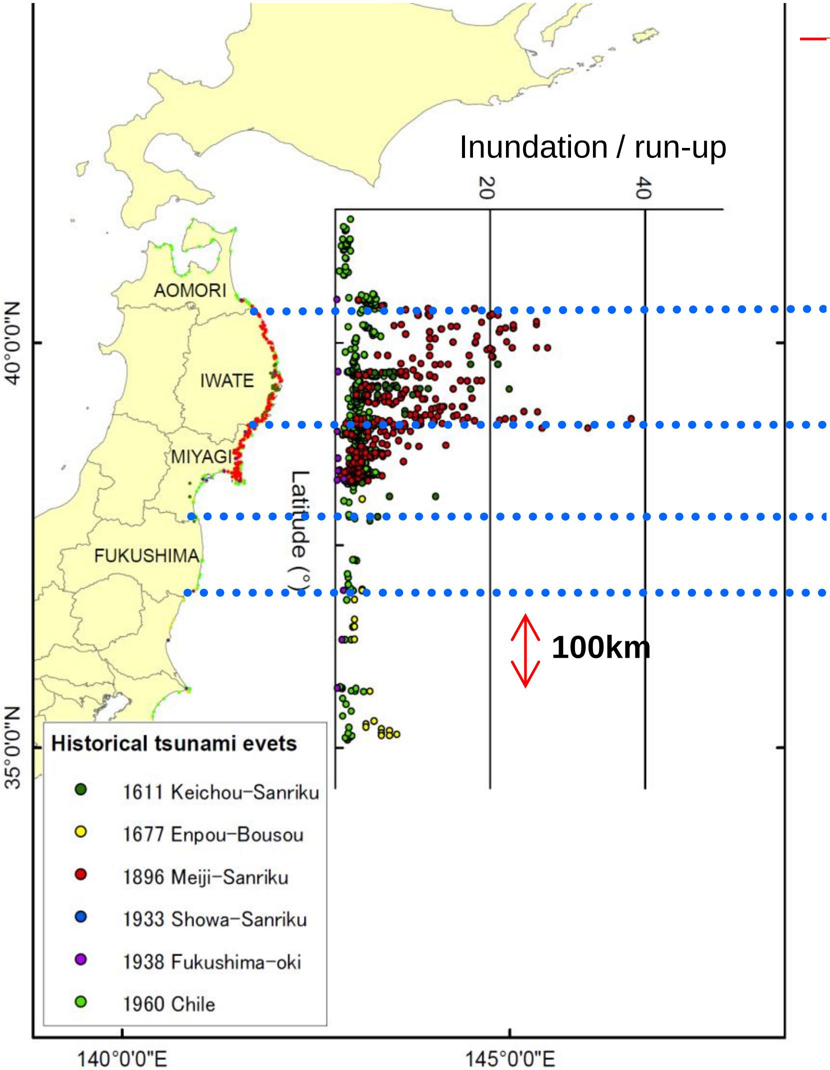
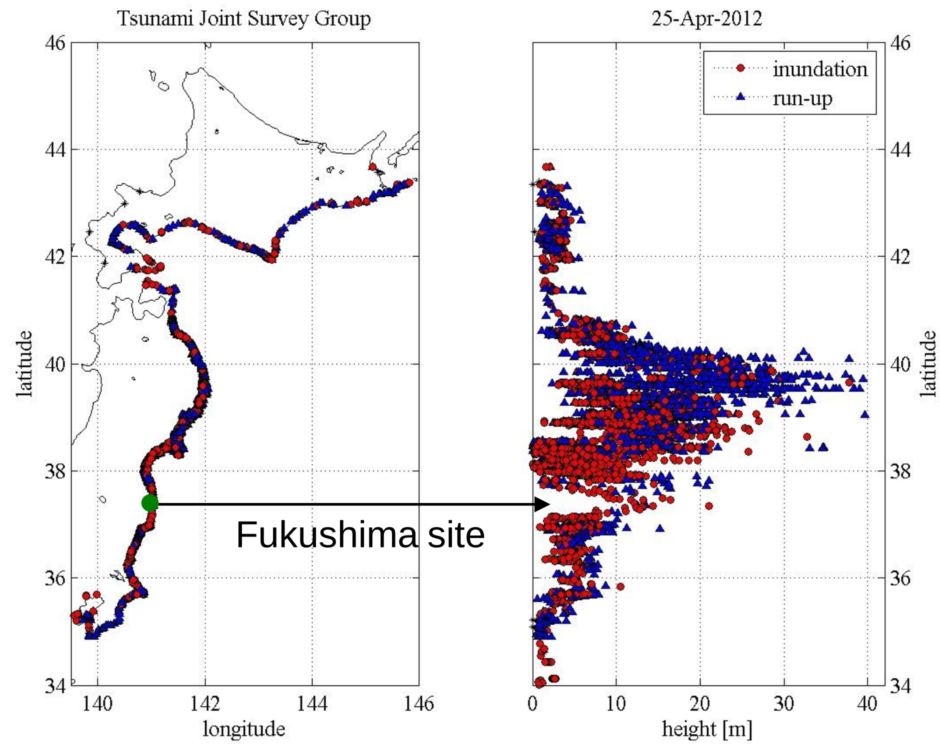


Fig. Tsunami height distribution after Edo era



There was no record of huge tsunami in Fukushima Pref.

Factor1 : Location of the tsunami source
Factor2 : Effect by topographic amplification

Factor1 : Location of the Tsunami Source

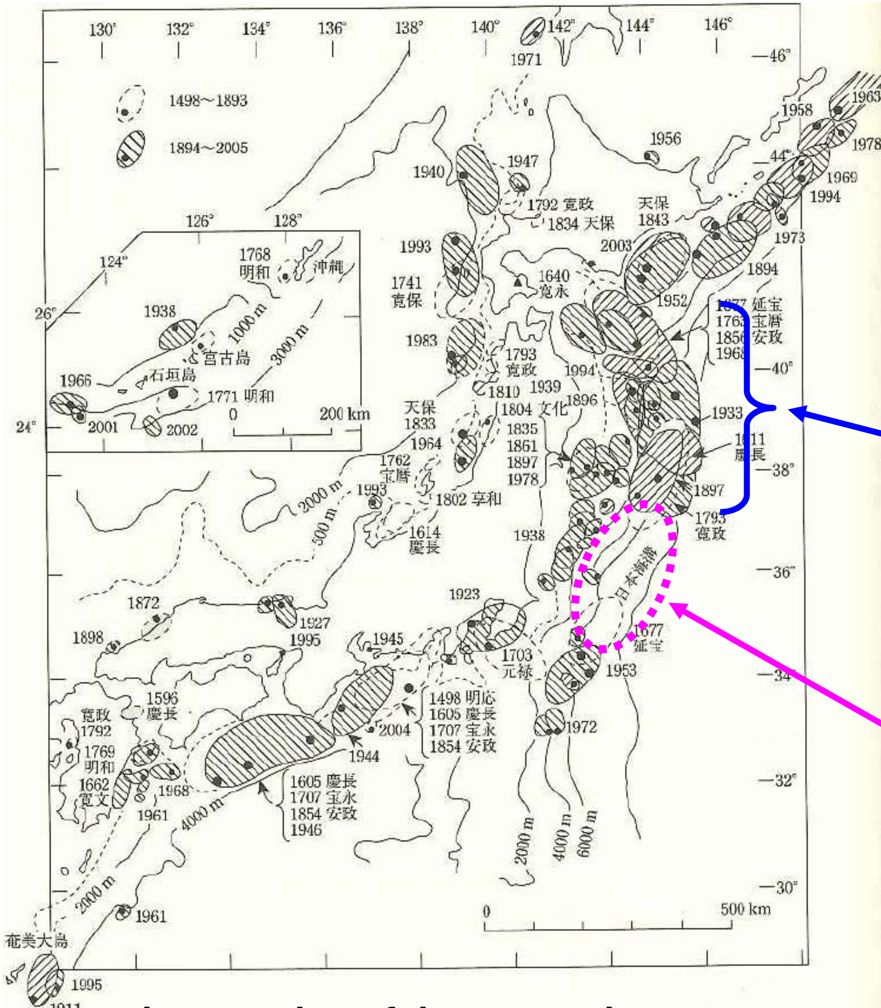


Fig. Location of the tsunami source

Touch in the materials by Shuto et al., 2007

1611	Keityo Sanriku	Mw8.6
1677	Enpou Bousou	Mw8.2
1896	Meiji Sanriku	Mw8.3
1933	Shouwa Sanriku	Mw7.9

- Historical tsunamis, especially over M8 earthquakes, mainly occurred in northern area of northern latitude of 38 degrees.

- There was no record about large earthquake along Japan Trench off the coast of the Fukushima Pref.

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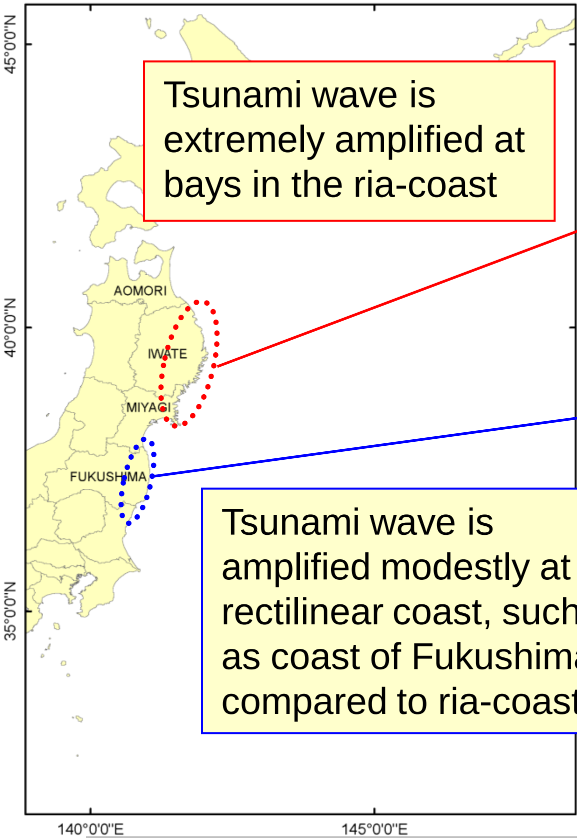
Factor2 : Effect by Topographic Amplification



Tsunami wave is extremely amplified at bays in the ria-coast

Tsunami wave is amplified modestly at rectilinear coast, such as coast of Fukushima, compared to ria-coast.

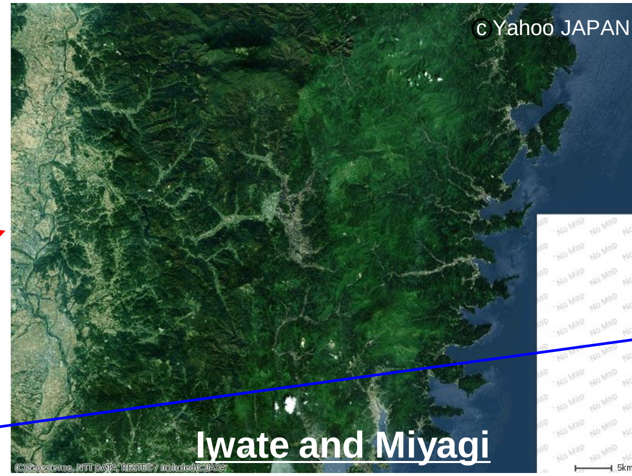
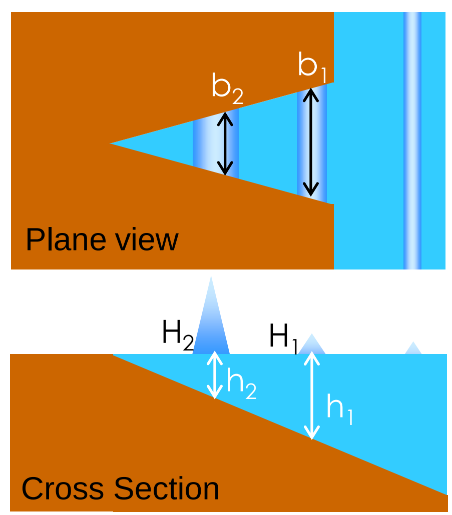


Fig. Topography along the coast



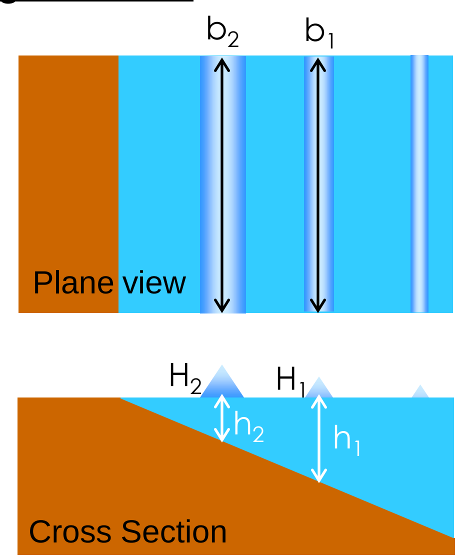


Fig. Schematic view of tsunami amplification

Green's Law

Tsunami height is amplified due to specific topography such as in V-shaped bay. (In this case b_1 > b_2)

$H_2/H_1=(h_1/h_2)1/4 \cdot$ **$(b_1/b_2)1/2$**

H_2, H_1 : height、h_1, h_2 : depth、b_1, b_2 : width

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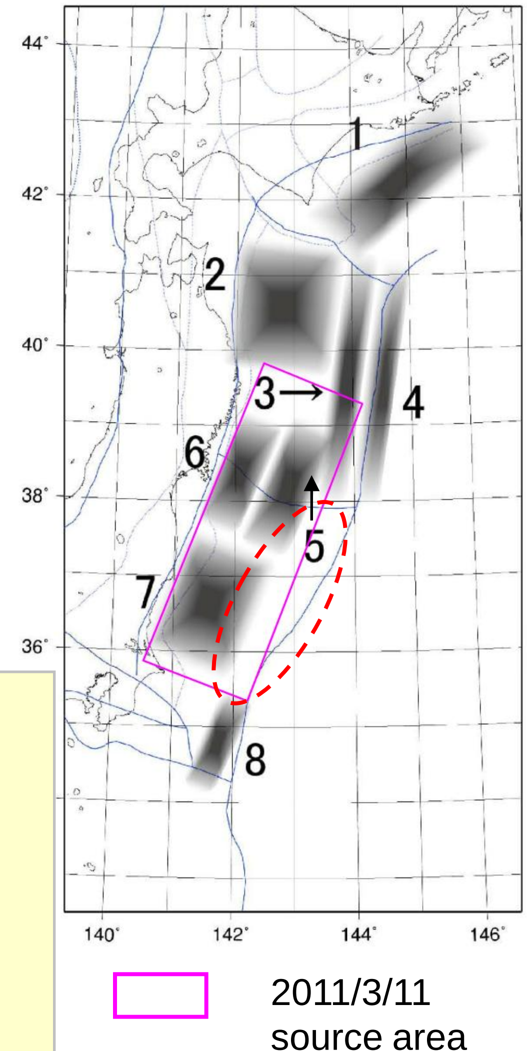
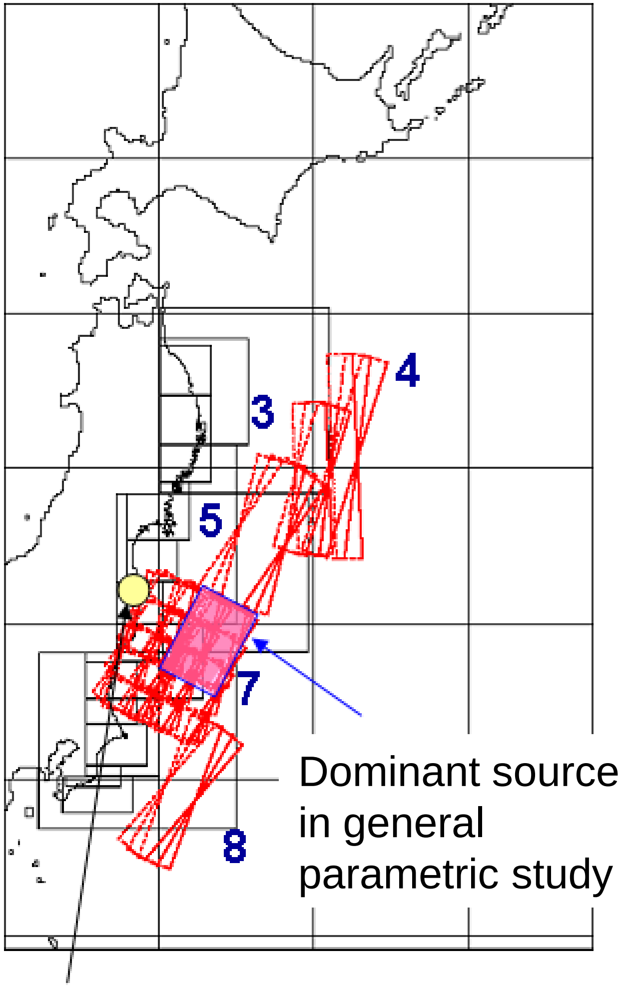
"Tsunami Assessment Method for Nuclear Power Plants in Japan (2002)" by JSCE (Japan Society of Civil Engineers)

No	Mw	Earthquake
1	8.2	1952 Nemuro-oki
2	8.4	1968 Tokachi-oki
3	8.3	1896 Meiji-Sanriku
4	8.6	1611 Keicho-Sanriku
5	8.2	1793 Miyagi-oki
6	7.7	1978 Miyagi-oki
7	7.9	1938 Fukushima-oki
8	8.1	1677 Enpo-Bousou



- Uncertainties, such as inexperienced event, are taken into account by parametric study of the standard fault model.
- Earthquakes are assumed in 8 areas individually for numerical simulation based on the historical tsunamis.
- Earthquake on March 11th occurred cross over several areas, that was not predicted by any experts.
- JSCE 2002 did not consider the tsunami source in the area along the trench of off the coast of Fukushima prefecture.

Parametric Study in the Near Field



Fukushima Daiichi NPS
Fukushima Daini NPS

3	Mw 8.3
4	Mw 8.6
5	Mw 8.2
7	Mw 8.0
8	Mw 8.2

General parametric study
- location
- strike

Detailed parametric study
- location - strike
- depth - dip angle
- slip angle

➢TEPCO carried out general parametric study for area 3, 4, 5, 7 and 8.

➢Tsunami from Area 7 was dominant, and detailed parametric study was conducted for this area.

➢Tsunami from Area 3 and 4, which corresponds to 1896 Meiji Sanriku Earthquake and 1933 Shouwa Sanriku Earthquake respectively, did not have an impact of Fukushima coast.

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Did Tepco's Countermeasures for Tsunami Lag Behind Other Electric Power Utilities?

	TEPCO		JAPC	Tohoku EPCO
Event	Fukushima Daiichi	Fukushima Daini	Tokai Daini	Onagawa
Ground Level of main buildings	O.P.+10 or 13m	O.P.+12m	H.P.+8.9m	O.P.+14.8m
published by Fukushima prefectural government	Countermeasure was unnecessary.	Countermeasure was unnecessary.		
Latest bathymetric and tidal data in 2009	O.P.+6.1m Countermeasure such as raise of the seawater pumps was completed.	O.P.+5.0m Countermeasure was unnecessary.	unexplained	unexplained
Tsunami in 2011	O.P.+13.1m (Tsunami height) O.P.+15.5m (Inundation height)	O.P.+9.1m (Tsunami height) O.P.+14.5m (Inundation height)	T.P.+5.4m	O.P.+13.8m

- **Assessment contents conducted by TEPCO were completely the same as Onagawa and Tokai.**
- **On March 11th , unprecedented simultaneous movement of several regions occurred in addition to the large fault slip.**
- **The resultant tsunami that struck Onagawa and Tokai NPP happened to be similar in height to that postulated based on the JSCE method.**
- **However, the tsunami that struck Fukushima Daiichi NPP happened to be considerably higher than that postulated based on the JSCE method.**

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Trial Calculation 1 in the Light of HERP in 2008

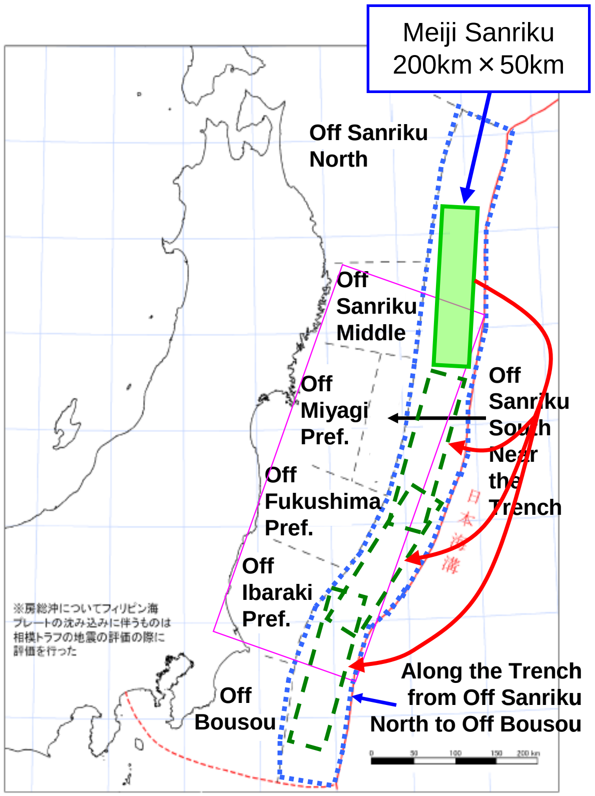


Fig. Earthquake region by the Headquarters for Earthquake Research Promotion (HERP)

Touch in the materials by HERP, 2002

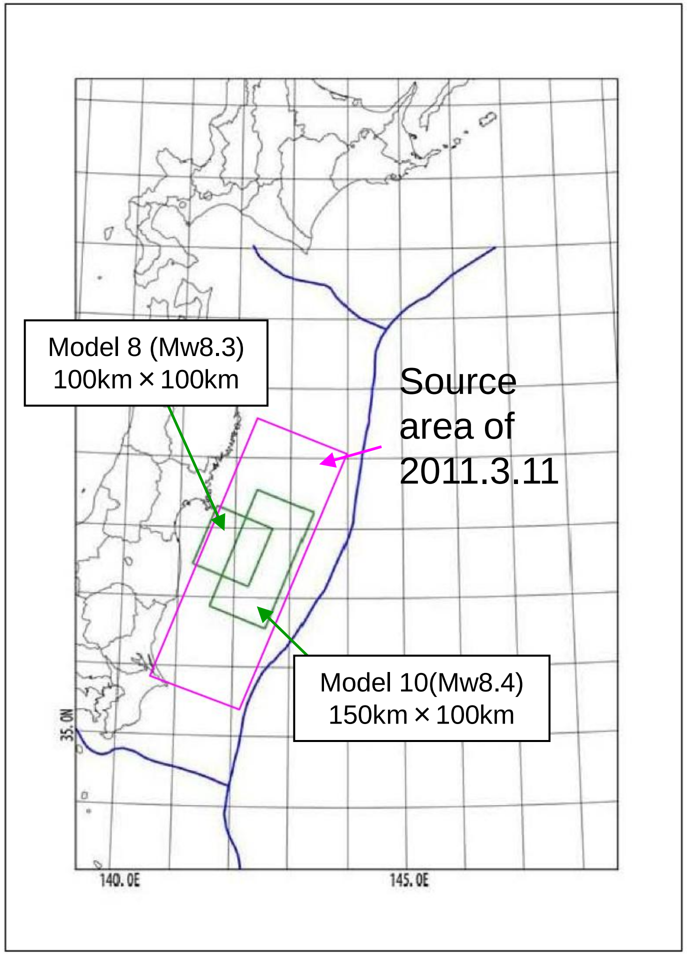
- The Headquarters for Earthquake Research Promotion **(HERP)** proposed in 2002 that **there is a possibility that M8.2 earthquake occur anywhere along the Japan Trench.**
- Prior to antiseismic back-check in the light of the seismic guideline, TEPCO carried out a trial calculation in deterministic way.
- HERP showed only the size of fault as 200km×50km and its magnitude as 8.2.
- **HERP** did not carry out tsunami simulation, and also **did not show the parameters which was necessary for tsunami calculation.**
- As tsunami source model had not been determined, **TEPCO hypothetically applied the model of Meiji Sanriku Earthquake Tsunami in 1896.**
- Its magnitude is Mw 8.3, which is larger than the magnitude 8.2 shown by HERP.

	1F							
unit	1	2	3	4	5	6	Northern part (O.P.13m)	Southern part (O.P.10m)
Tsunami Hight [m]	8.7	9.3	8.4	8.4	10.2	10.2	13.7	15.7

	2F				
unit	1	2	3	4	(O.P.12m)
Tsunami Hight [m]	7.6	7.2	7.8	8.2	15.5 (Southern part)

Run-up Height

Trial calculation 2 of Jogan Tsunami



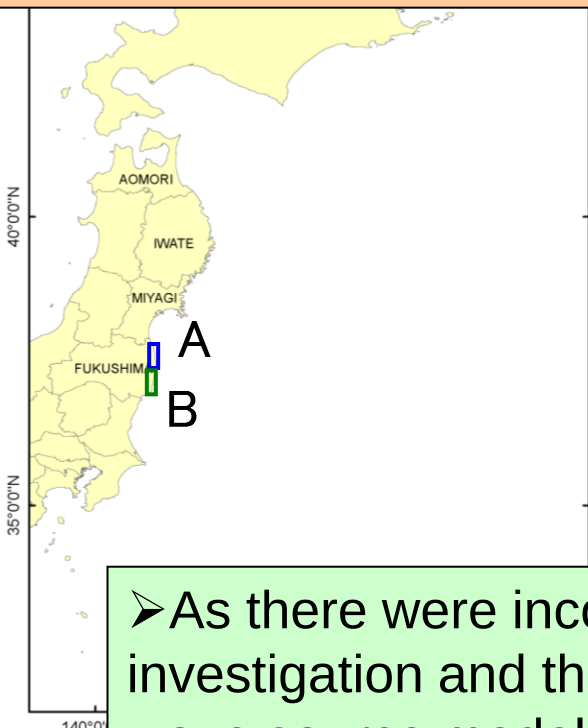
- TEPCO conducted trial calculation of Jogan Tsunami using the magnitude and location etc. proposed by Satake et al.(2008).
- The model proposed by Satake(2008) was the first-ever model for tsunami calculation based on tsunami deposit survey results.
- Satake et al.(2008) pointed out that **they could not determine the fault parameters because of lack of information**, then **they mentioned the additional tsunami deposit survey should be carried out.**
- Therefore TEPCO decided to perform the tsunami deposit survey in accordance with the indication.

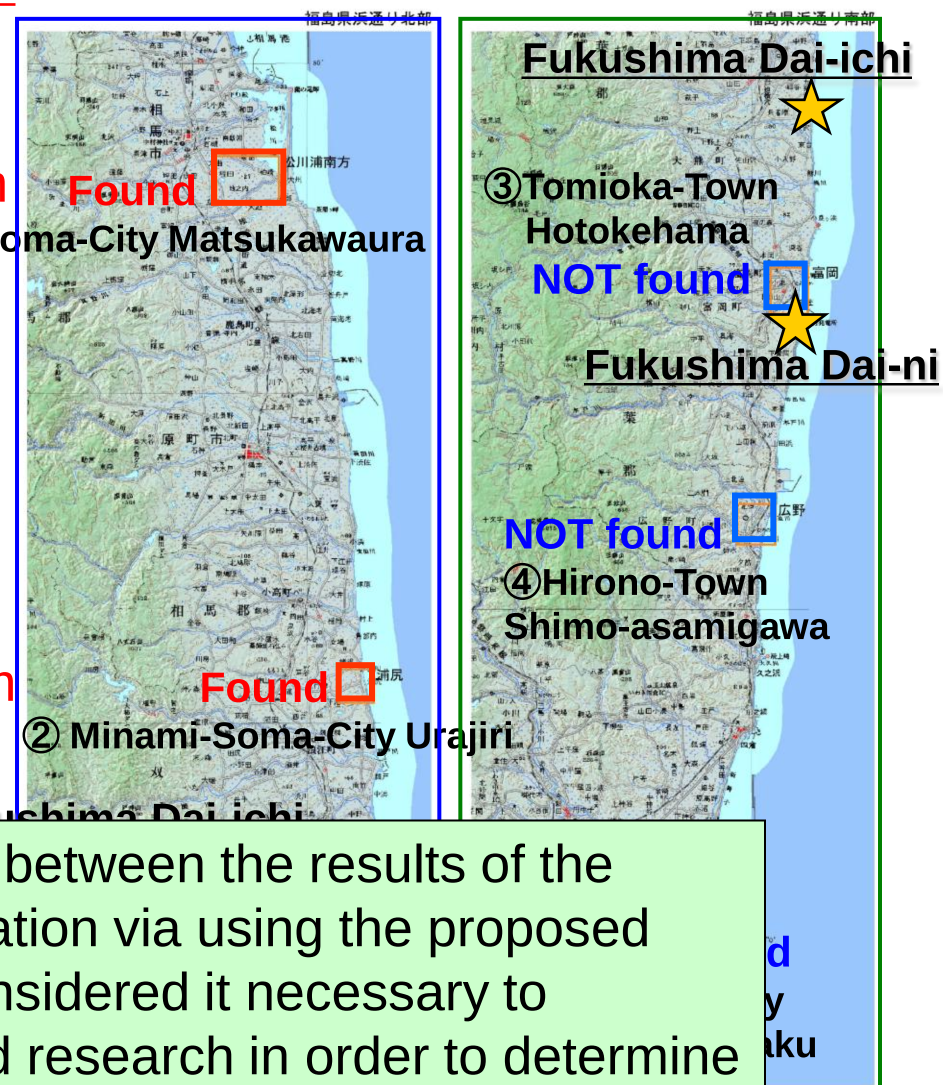
	1F							
Unit	1	2	3	4	5	6	Northern part (O.P.13m)	Southern part (O.P.10m)
Tsunami height [m]	8.7	8.7	8.7	8.7	9.1	9.2	No inundation	No inundation

	2F				
Unit	1	2	3	4	(O.P.12m)
Tsunami height [m]	8.0	7.8	7.8	7.9	No inundation

Tsunami Deposit Survey by TEPCO

To understand Jogan tsunami further, core boring was also performed at five locations in Fukushima Prefecture from 2009 to 2010.





➢As there were inconsistencies between the results of the investigation and the trial calculation via using the proposed wave source model, TEPCO considered it necessary to conduct further investigation and research in order to determine the wave source of Jogan tsunami.

eposit survey in Fukushima coast by TEPCO

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Review for HERP / Jogan by JSCE

1. TEPCO did not take immediate actions based on results of HERP/Jogan trial calculations because:
   - ➢There was no record of M8-level large earthquake off the coast of Fukushima.
   - ➢ Not only JSCE but also CDMC and prefectural governments did not consider the tsunami source off the coast of Fukushima
   - ➢ Jogan tsunami source had not been determined and that additional tsunami deposit survey was needed.
2. TEPCO thought that the appropriateness of the tsunami source models should be reviewed by experts.

Year	Contents	Remarks
2009	Request for revising JSCE method from TEPCO	Revised JSCE method was scheduled to be applied to the anti-seismic back-check on the basis of the new regulatory guide for seismic design revised in 2006.
2009 ~2012	Discussion issues in the Tsunami evaluation committee of JSCE 1) fault model of tsunami source 2) numerical simulation methodology 3) consideration of uncertainties 4) others	In 2009, electric utilities including TEPCO have requested that JSCE review the suitability of the tsunami sources. Discussion on the idea proposed by Headquarters for Earthquake Research Promotion and the paper regarding Jogan tsunami are included in discussion issues (see left column)
2013	Publication of revised JSCE method (planned → postponed)	About three years were needed to publish the first version of the JSCE method (2002).

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2. Tsunami Height Estimation
- Lesson1

- Why we could not predict a large Tsunami
- Why we could not prevent important electric facilities from flooding
- How our organization can be more robust against natural hazards

INPO Special Report says

Lessons Learned from the Fukushima Accident are:

- When periodic reviews or new information indicates the potential for conditions that could significantly reduce safety margins or exceed current design assumptions, a timely, formal, and comprehensive assessment of the potential for substantial consequences should be conducted.
- An independent, cross-functional safety review with a plant walkdown should be considered to fully understanding the nuclear safety implications.
- If the consequences could include the potential for common-mode failures of important safety systems, compensatory actions or countermeasures must be established without delay.

My Personal Thoughts and Reflections

I personally wonder and reflect:

- if we had an owner totally in charge of risk on nuclear safety of our plants
- if we had the process or idea to set up the opportunity for discussing with tsunami experts, safety experts, electrical experts, mechanical experts all together for cross-functional safety review, when we encountered the trial calculation result (15.7m)
- if we put more importance on probability rather than consequence
- if we focused more on QMS related activities rather than vulnerability analysis and safety enhancement
- why we could not more effectively learn the lessons from international operational experiences, such as flooding at Blayais NPS, France
- why we could not take any compensatory measures, such as making safety related electric facilities watertight, instead of trying to take perfect countermeasures

INPO Special Report also says:

The following questions are provided from safety culture viewpoints:

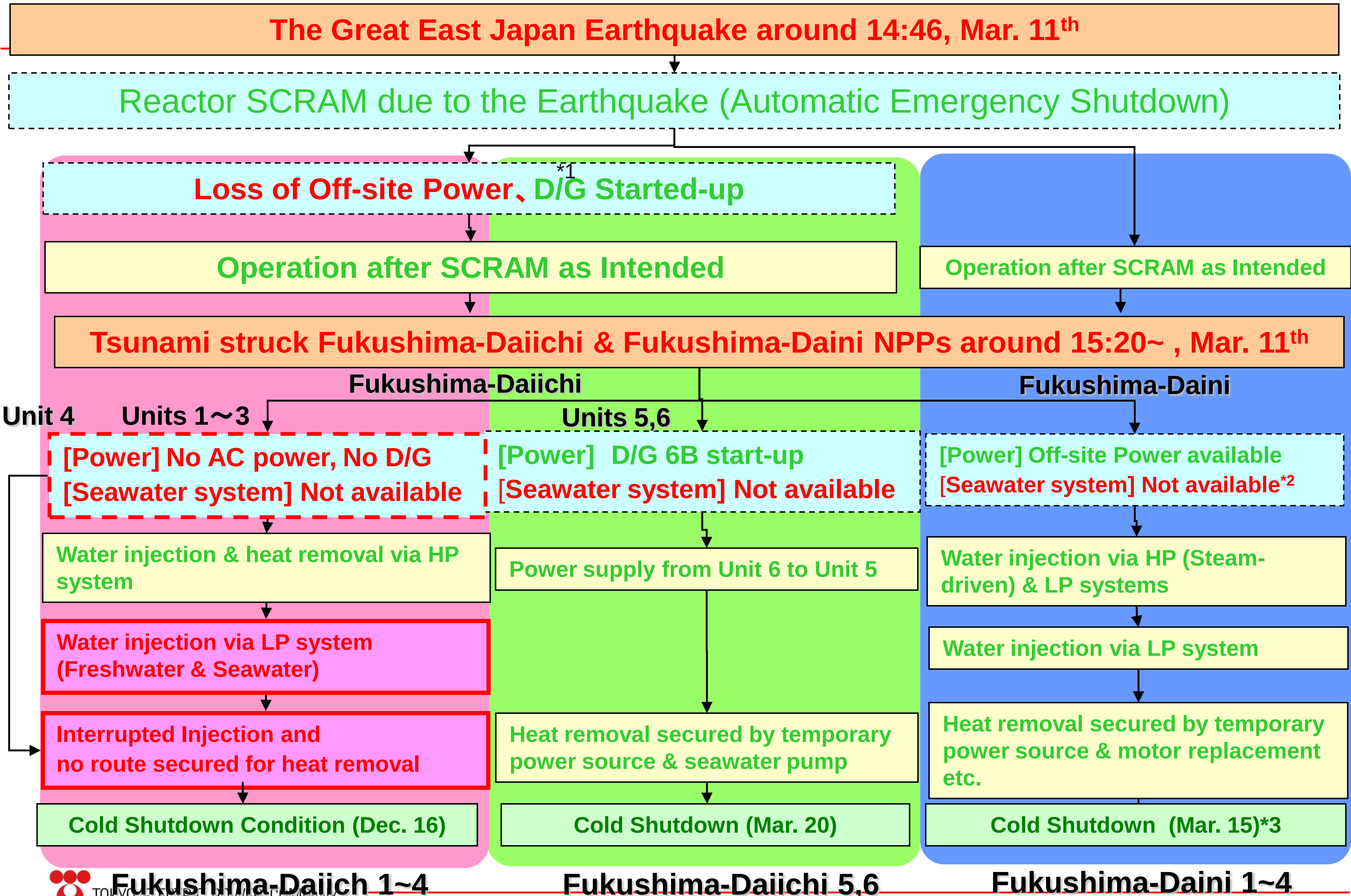
- How rigorous are your approaches for problem-solving, determining nuclear safety implications, and taking conservative actions when information is incomplete or inconclusive and the potential consequences of a situation are not fully understood?
- How does your organization promote a sense of ownership for resolving potential nuclear safety issues in a timely manner, rather than delegating these issues to outside organizations or regulatory agencies?
- How thorough are discussions of issues that potentially impact nuclear safety, and to what extent are the safety implications considered during enterprise business planning and budgeting?

3. How we responded in the Recovery Process ?

Facts

- What difficulties existed
- What were effectively utilized

Sequence of Events after the Earthquake



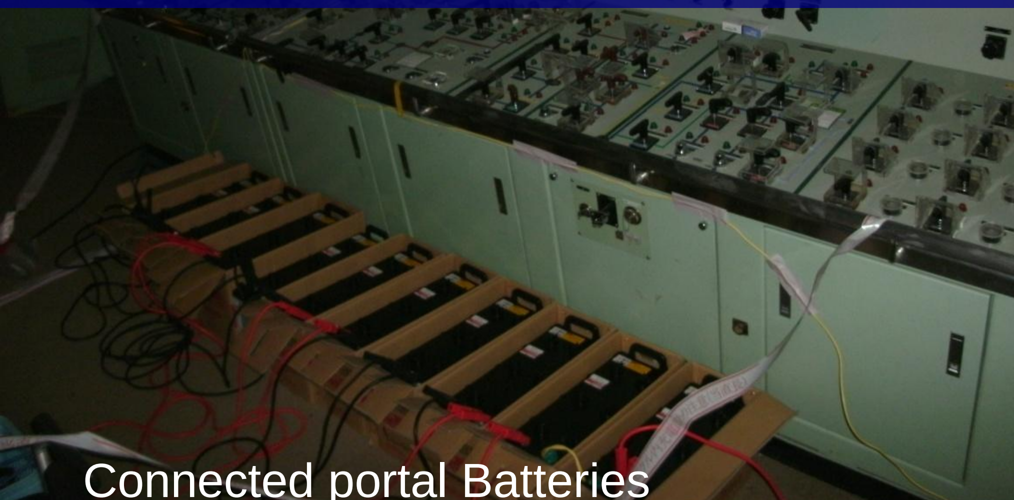
*1 D/G：Emergency Diesel Generator *2 RHR Seawater System *3 Fukushima-Daini Emergency State was Lifted on Dec.26th

Response in Dark Control Room

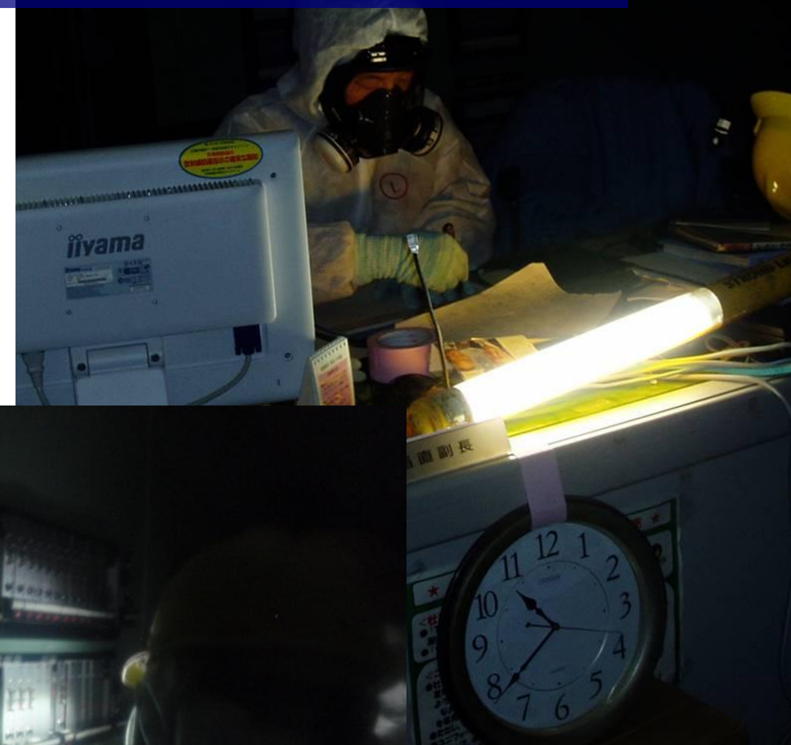
Shift Supervisor's Voices

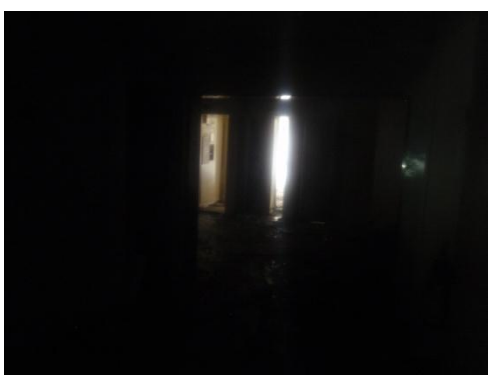
・When the power source failed, I felt completely helpless.

・Heated discussions broke out among the operators regarding whether it was important to remain in the control room or not.



Connected portal Batteries



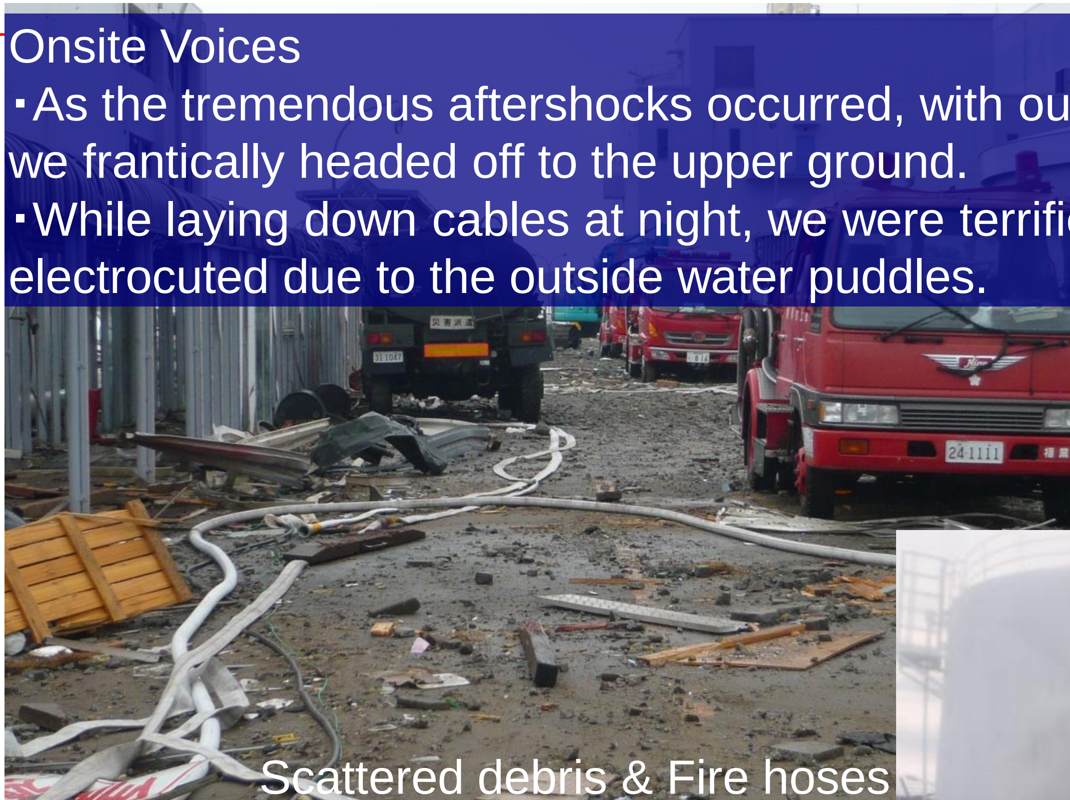


Difficult to Access

Onsite Voices

・As the tremendous aftershocks occurred, with our full face masks still on, we frantically headed off to the upper ground.

・While laying down cables at night, we were terrified that we might be electrocuted due to the outside water puddles.



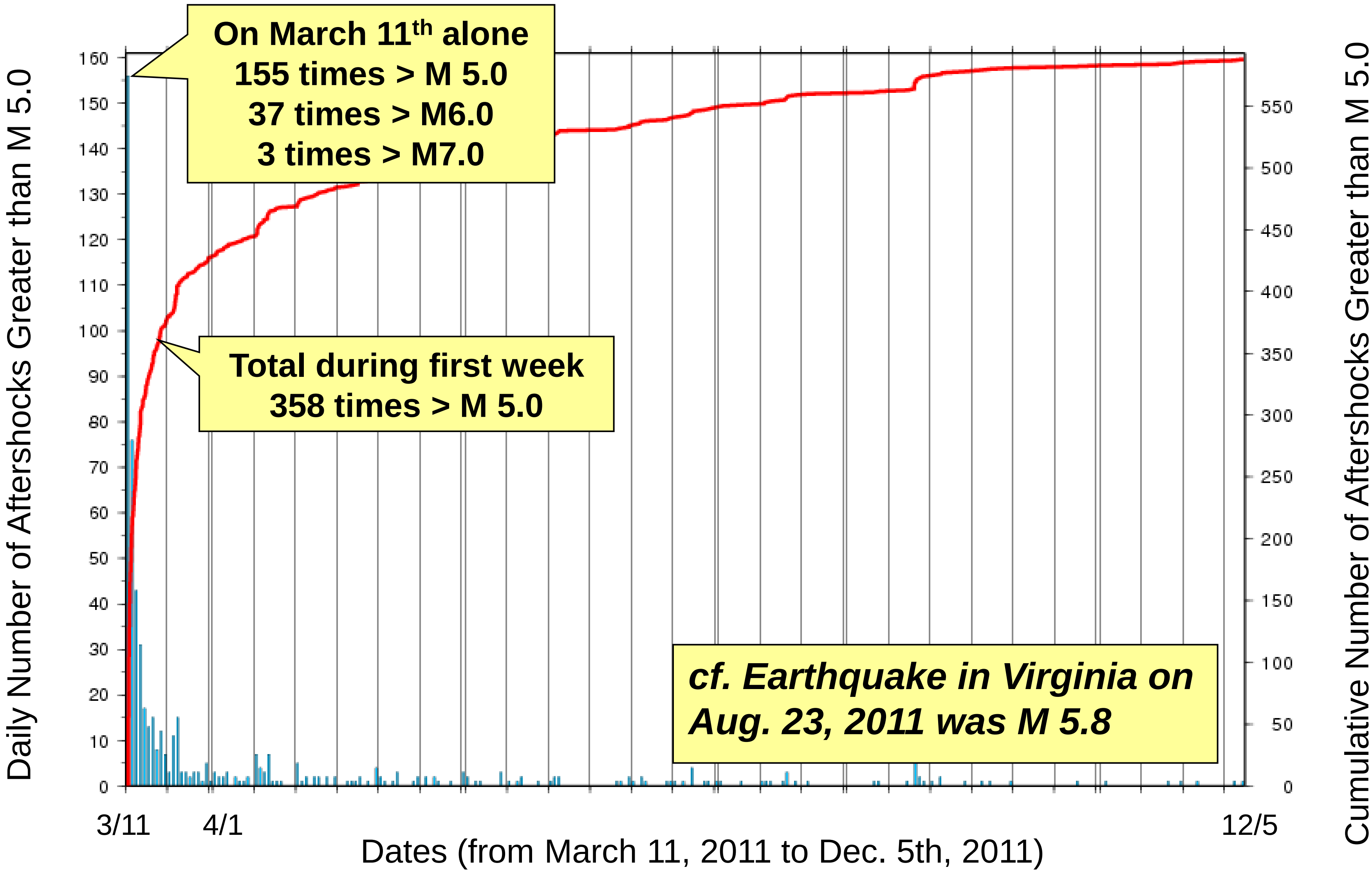
Scattered debris & Fire hoses

Wide crevices around there

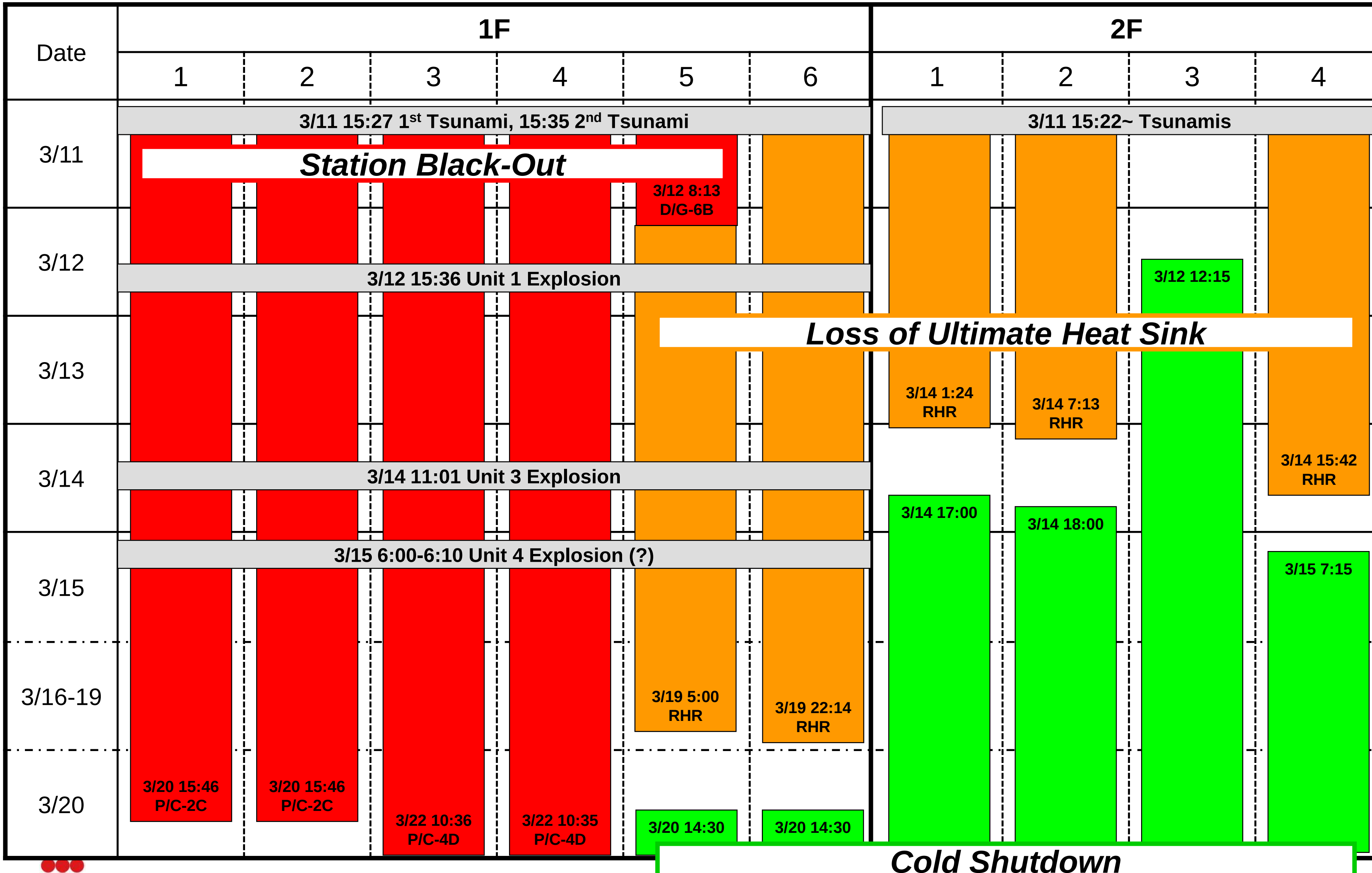
Water injection by Fire Engine

Tank adrift on the road

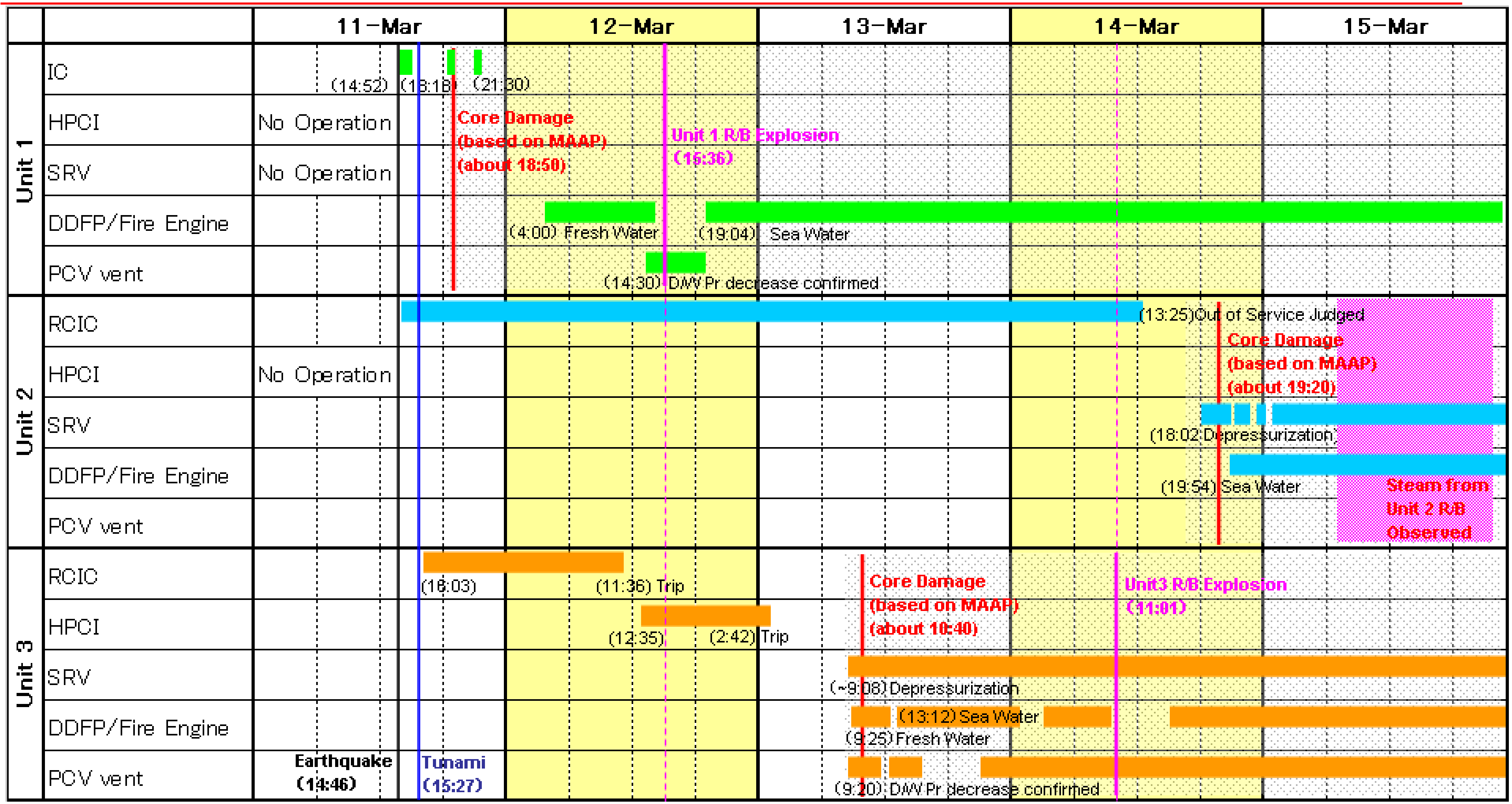
Number of Aftershocks Greater than M 5.0



Overview of the 10-Unit Simultaneous Accidents



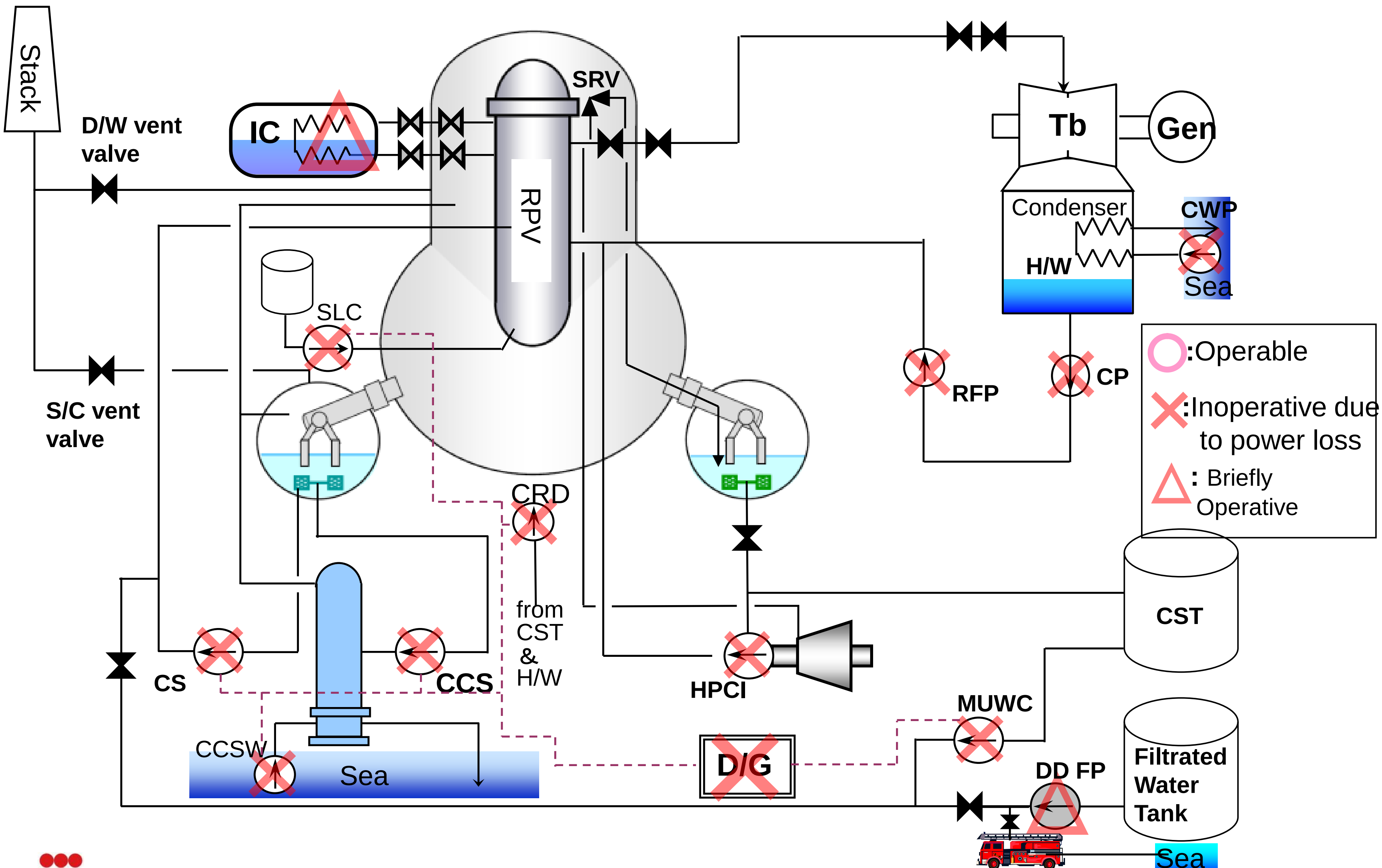
Summary of Accident Progression



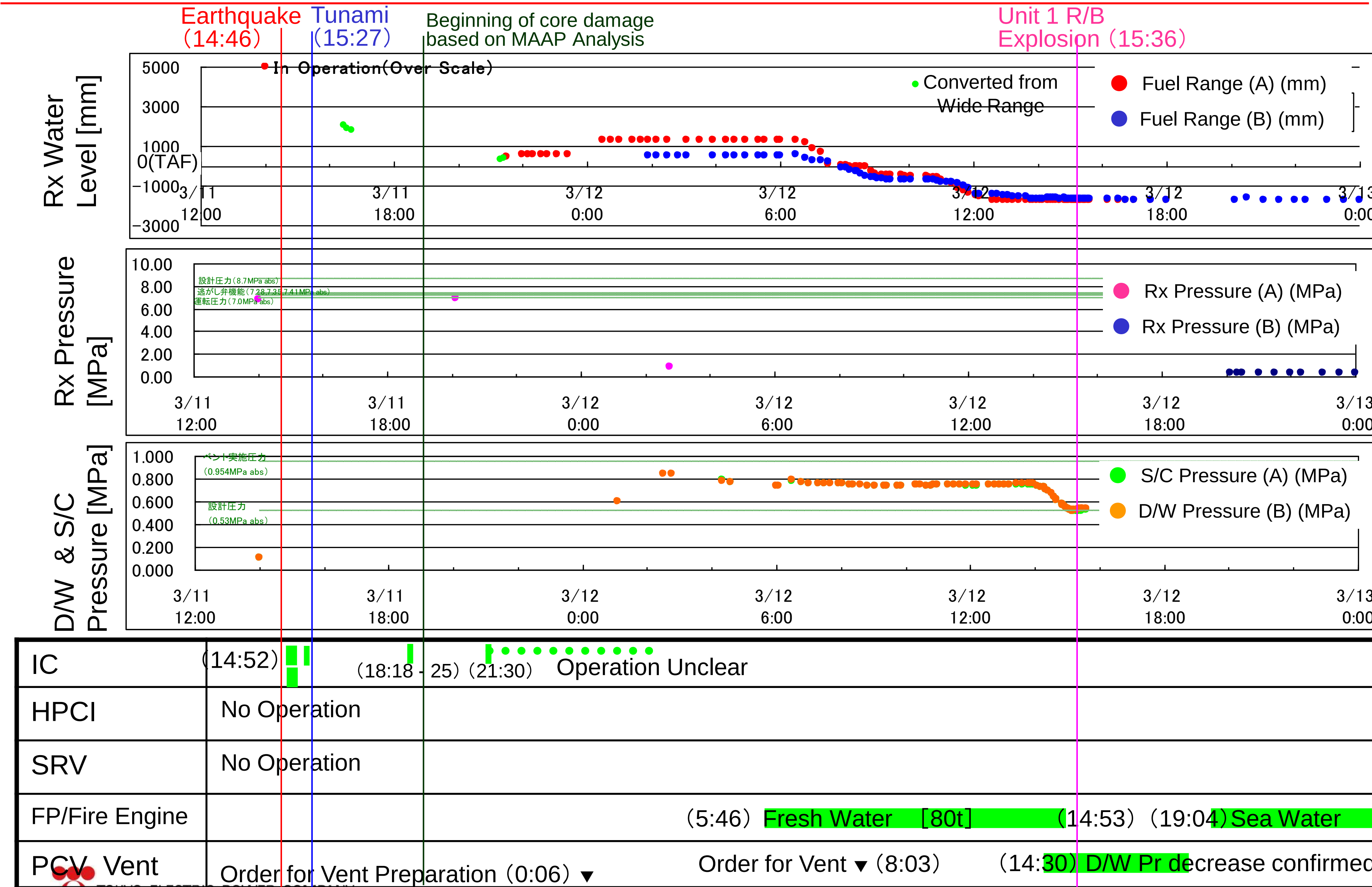
- Crisis's occurred sequentially starting from Unit 1, Unit 3, and then Unit 2
- Shortly after cooling function was lost, core damage started and was followed by containment damage at each unit

TOKYO ELECTRIC POWER COMPANY

1F Unit 1 Schematic System Diagram (After Tsunami)



1F Unit 1 Plant Parameter and Operation



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Why Operators and ERC couldn't Recognize IC Operation Status Clearly?

Chronology

- ✓ **At 16:42:** Water level indication temporarily restored as **above TAF+25cm**, that was **decreasing**.
- ✓ **At 16:44: ERC personnel confirmed steam from IC exhaust pipe.**
- ✓ **At 17:50:** Operators were dispatched to reactor building. However they couldn't reach there and **returned because of unusual radiation dose.**
- ✓ Valve position indicator of **outboard valves (MO-2A and MO-3A)** illuminated and showed they were **closed.** (status of inboard valves was unknown)
- ✓ **At 18:18: Operators opened outboard valves. Steam from IC exhaust pipe was confirmed**. This operation was reported to ERC. However, steam became no longer visible shortly thereafter.
- ✓ **At 18:25:** Operators became concerned IC cooling water could be lost. **Operators closed outboard valves(MO-3A)** because it was thought that IC was not functioning and there was no measure to refill cooling water. **This operation was not reported to ERC.**
- ✓ **At 21:10: Operator opened outboard valve(MO-3A),** considering capacity of cooling water is enough to operate IC for about 10 hours without supply and DDFP had become operable and could supply cooling water. **Steam from IC exhaust pipe was confirmed.**
- ✓ **At 21:19:** Water level indication was restored. Water level was **TAF+20cm**
- ✓ **At 23:50: PCV pressure gauge** was restored as **600MPa**. ERC thought IC could not be operating.

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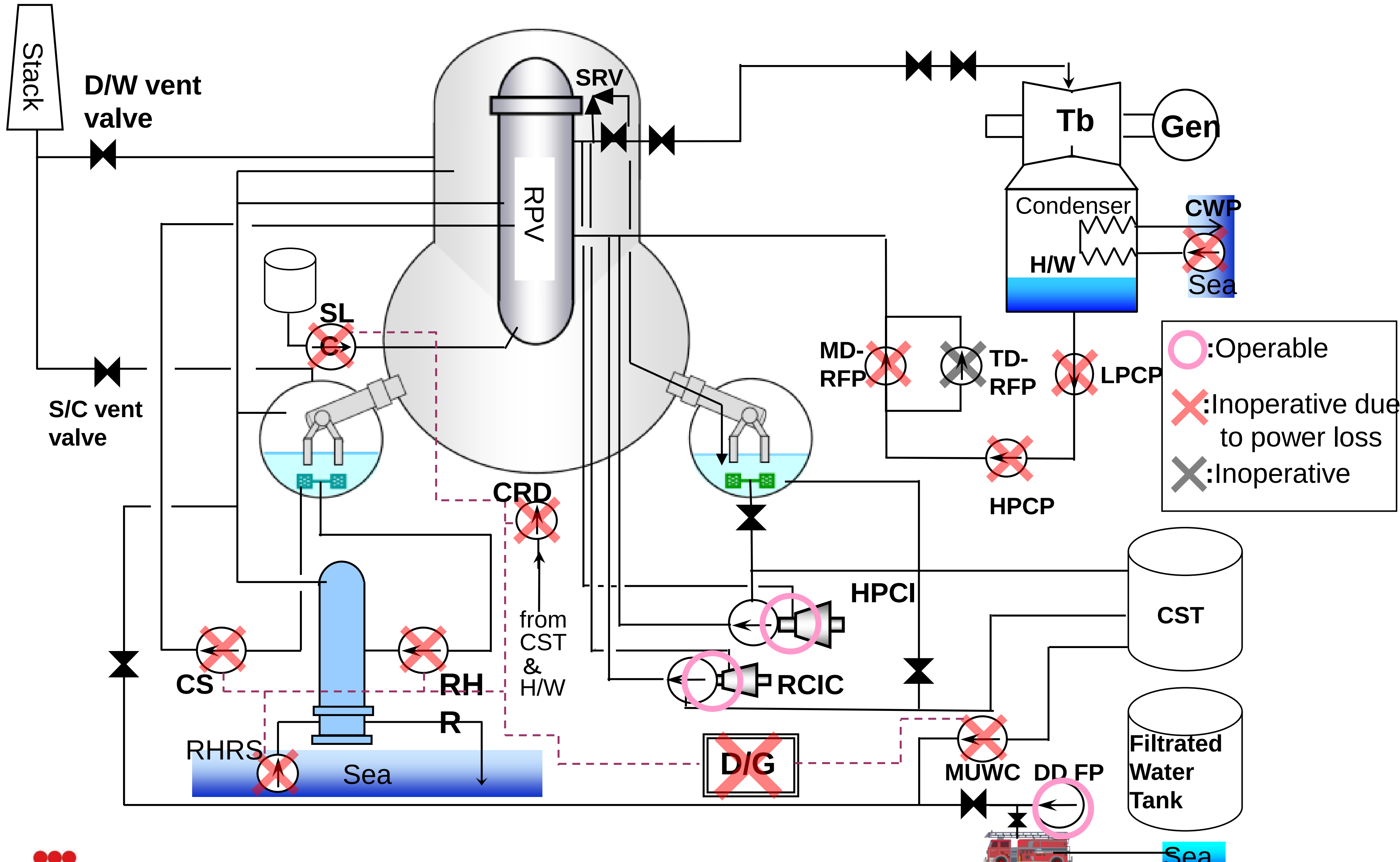
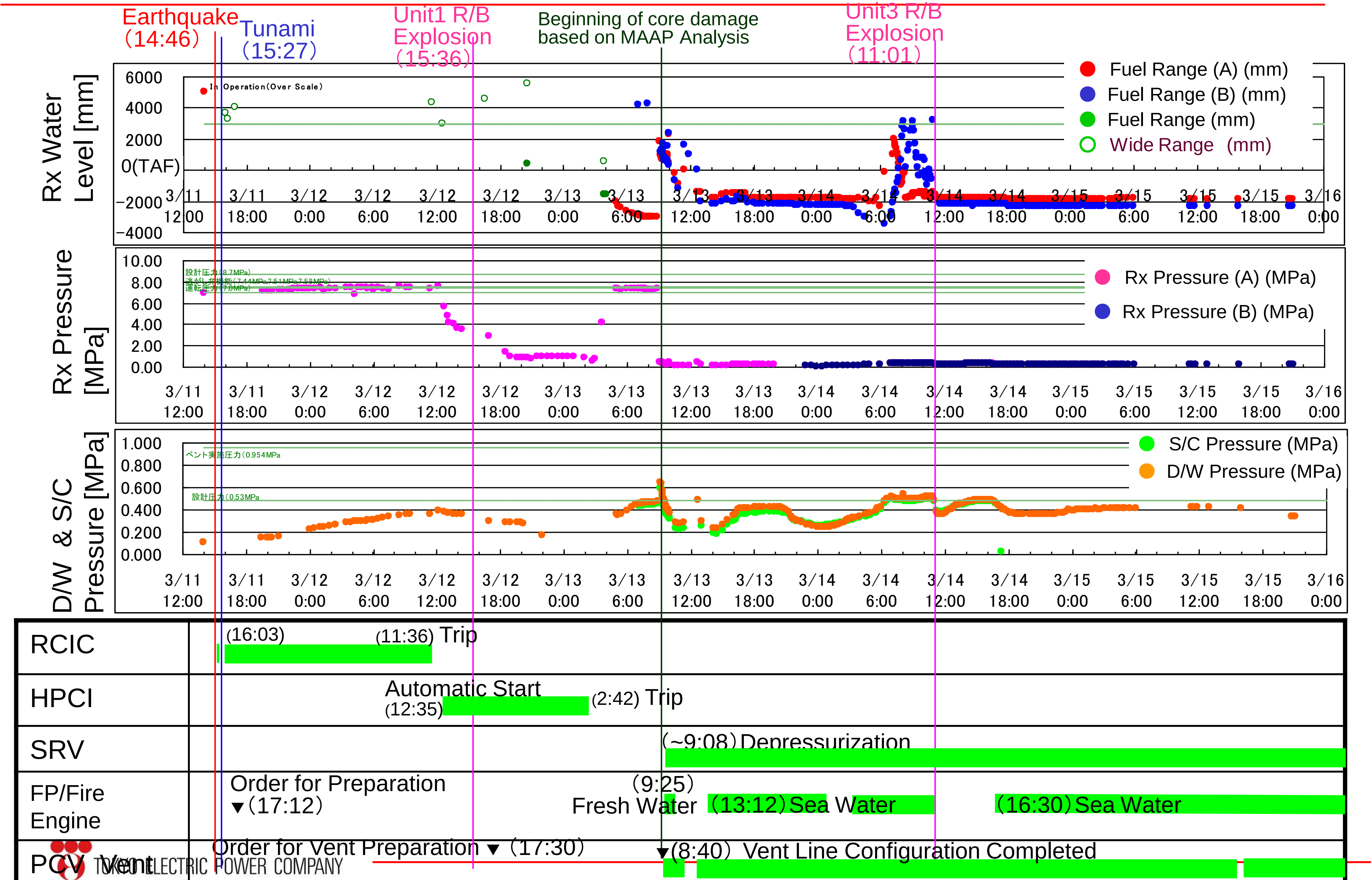
TEPCO

1F Unit 3 Schematic System Diagram (After Tsunami)



1F Unit 3 Plant Parameter and Operation



TOKYO ELECTRIC POWER COMPANY

Transfer to Low Pressure Water Injection at Unit 3

Chronology

- ✓ Though DDFP was started up while HPCI was operating, its discharge pressure was lower than the rated pressure for unknown reason.
- ✓ Proactive transfer to low pressure water injection was not challenged, because of low trust on DDFP.
- ✓ The reactor pressure went down and was out of the region where HPCI could be operated stably, and the injection flow rate went down.
- ✓ When HPCI was manually shut down, operators expected SRVs could be opened, because their position indicator lamps were lit, implying that DC power was still available.
- ✓ However SRVs couldn't be opened then.
- ✓ Shutdown operation of HPCI was conducted by operators and it was not reported to key decision makers at ERC until failure of SRVs opening was recognized.
- ✓ Batteries were collected from employees' cars and connected to control panel.
- ✓ SRVs were opened, and water injection was initiated using DDFP and fire engine.
- ✓ Before initiation of low pressure water injection, core was damaged.

3. How we responded

Lesson2

- Why we could not prevent our plants from core damage

- How our organization can be more robust under emergency situation

INPO Special Report says

Lessons Learned from the Fukushima Accident are:

- Ensure that, as the highest priority, core cooling status is clearly understood and that changes are controlled to ensure continuity of core cooling is maintained.
- If core cooling is uncertain, direct and timely action should be taken to establish conditions such that core cooling can be ensured.
- Optimum accident management strategies and associated implementing procedures should be developed through communications, engagement, and exchange of information among nuclear power plant operating organizations and reactor vendors.
- On-shift personnel and on- and off-site emergency responders need to have in-depth accident management knowledge and skills to respond to severe accidents effectively.

My Personal Thoughts and Reflections

I personally wonder and reflect:

- why any leaders in the ERC did not positively speak out to clearly determine the operational status of IC of Unit 1 understanding it is the last resort to save the plant. Same as for HPCI of Unit 3
- how effectively command and control worked to cope with multi-unit events
- some of key decision makers in the ERC did not necessarily have expertized knowledge and skills to develop clear strategies to respond to the unexpected event and to provide operators and maintenance people with specific directions
- how many of them had been trained enough to take such roles
- if we had been brushing up the sense of thorough focus on safety, while QMS focus was sometimes not productive and just time-consuming under the ineffective influence from our regulatory body
- how rigorously we made efforts to integrate safety-first concept into routine work process

INPO Special Report also says:

The following questions are provided from safety culture viewpoints:

- How does your organization avoid "group think" or accepting unverified assumptions when making decisions that could affect nuclear safety?
- How would your organization provide the needed level of questioning and challenging of assumptions so that continuity of core cooling and containment integrity are ensured during a complex event?
- What additional approaches are used during an event when important decisions must be made relatively quickly?
- When discussing issues that could affect plant safety or reliability, how effective is your organization in asking "What is the worst that could happen?" ?

4. Safety Improvement and Further Enhancement of Nuclear Safety

Power Cables

Air-cooled and on-board Gas Turbine Generator (4500kVA)

Basic Concept of Safety Improvement Measures for TEPCO NPP

○Flooding protection measures to cope with tsunami

In order to prevent tsunami causing the submergence of safety critical equipment and functional loss, flooding protection measures are taken mainly for reactor buildings. Drainage systems are also provided as a precaution.

○Fuel damage prevention measures during SBO or loss of heat sink

Materials and equipment are stored at high places in plant premises to prevent damage to the fuels in reactors and SFPs even during SBO or LUHS (heat removal function), and flexible procedures provided for an effectively use of these materials and equipment.

○Effect mitigation measures provided as a precaution for fuel damage

A **top vent** is installed for preventing hydrogen explosions following a bare possibility of fuel damage. For ensuring preparations, a **filter vent** is also installed to mitigate radiation impact on the environment.

○Common measures

Materials and equipment critical for supporting the restoration of reactor facilities following an accident, and a system of using them are provided.

Immediate Safety Measures at Kashiwazaki-Kariwa NPS

Spare pump for sea water pump
- Submerged pumps
- Spare hoses

To Depressurize RPV
- Spare gas cylinders

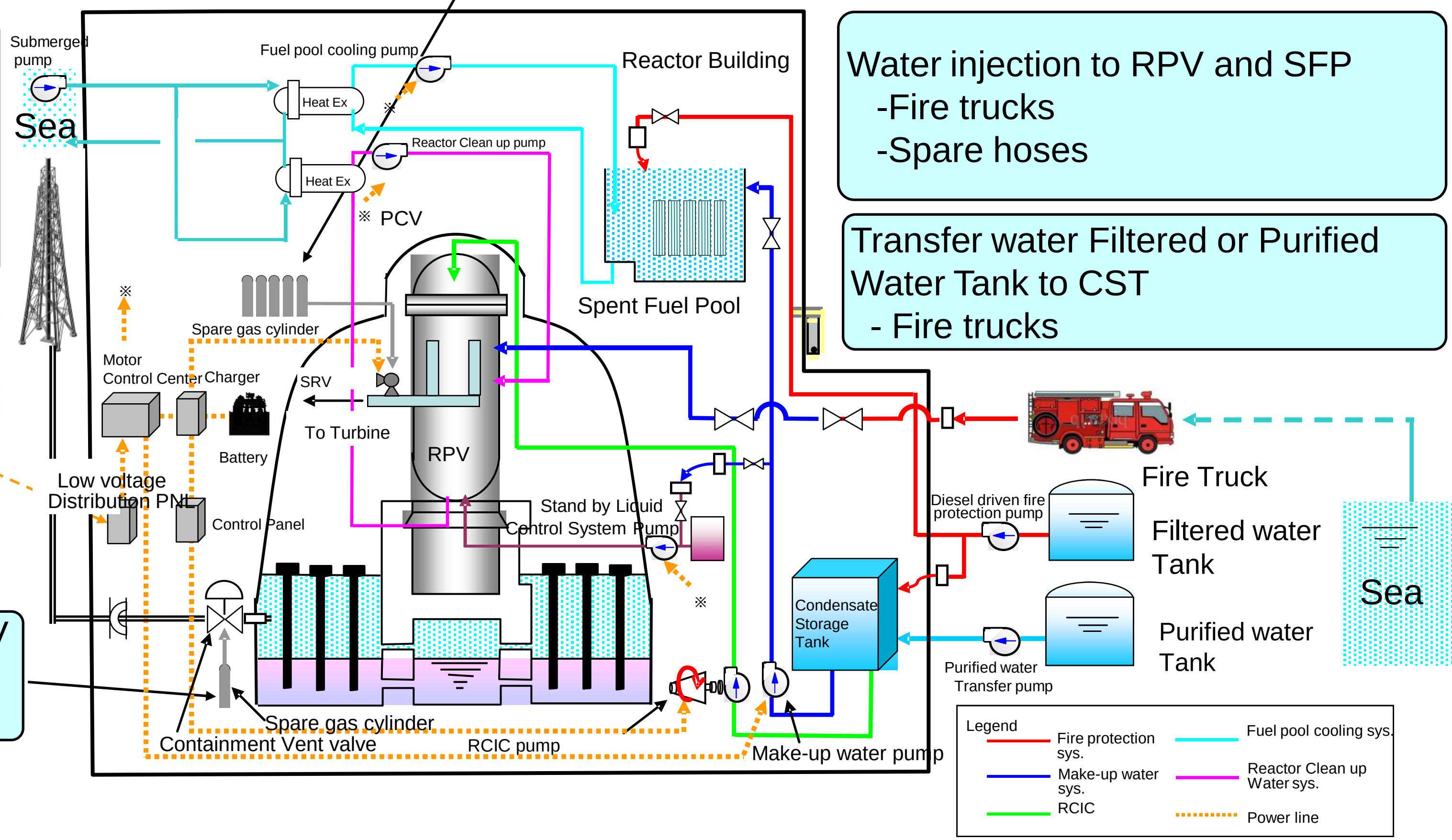
Emergency Power Supply Capability under Tsunami SBO
- High voltage power trucks
- Portable generators
- spare cables

Mobile power trucks

To Depressurize PCV
- Spare gas cylinders

Water injection to RPV and SFP
- Fire trucks
- Spare hoses

Transfer water Filtered or Purified Water Tank to CST
- Fire trucks

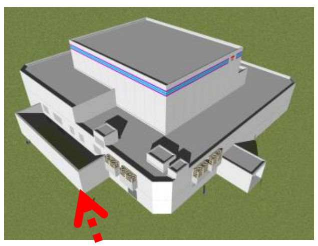


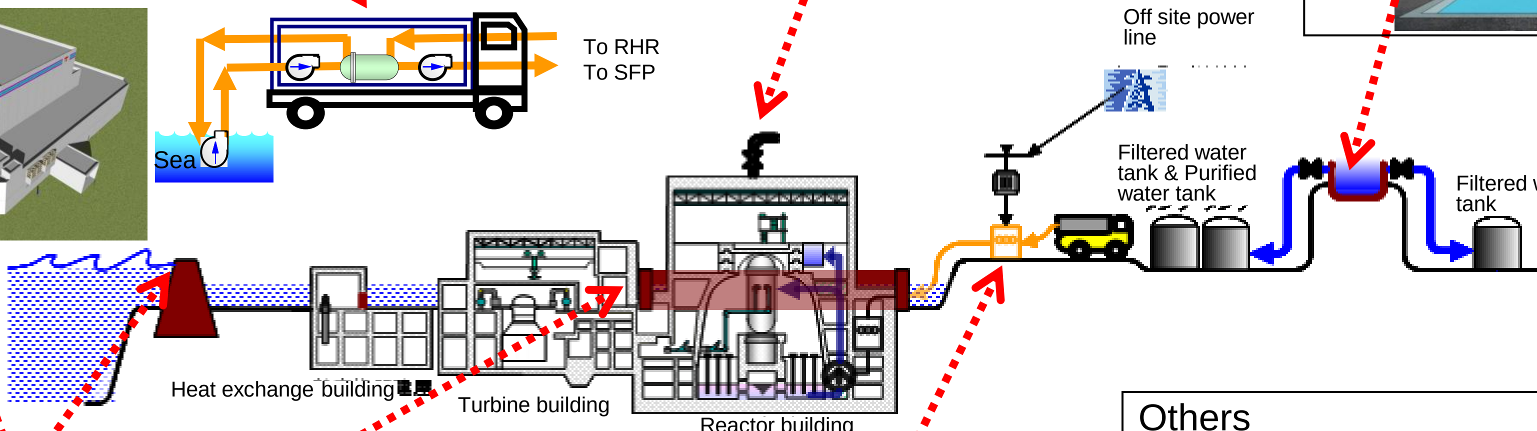
Further Safety Measures at Kashiwazaki-Kariwa NPS

Enforcement of injection and heat removal
- Submerged pump
- Heat exchanger truck
- Spare hose

Prevention of accumulating Hydrogen
(1)Top vent on Reactor Building

Enforcement of injection and heat removal
(2)Reservoir on site.





Enforcement of protection for flooding
(1)Embankment
(2)Wall
(3)Water-tight doors in Reactor Building

Enforcement of power source
(1)GT-driven generator truck
(2)Emergency high voltage distribution panel
(3)Cable from emergency high voltage panel for RHR

Others
(1) Additional monitoring cars

(2) Additional warehouse for emergency materials on the hill

Direction of Nuclear Reform

✓ Emergency Preparedness

- Consideration of Multi-Unit Event
- Resource Management
- Command and Control - Roles and Responsibility
- Radiological Protection and Control
- International Cooperation

✓ Risk Management

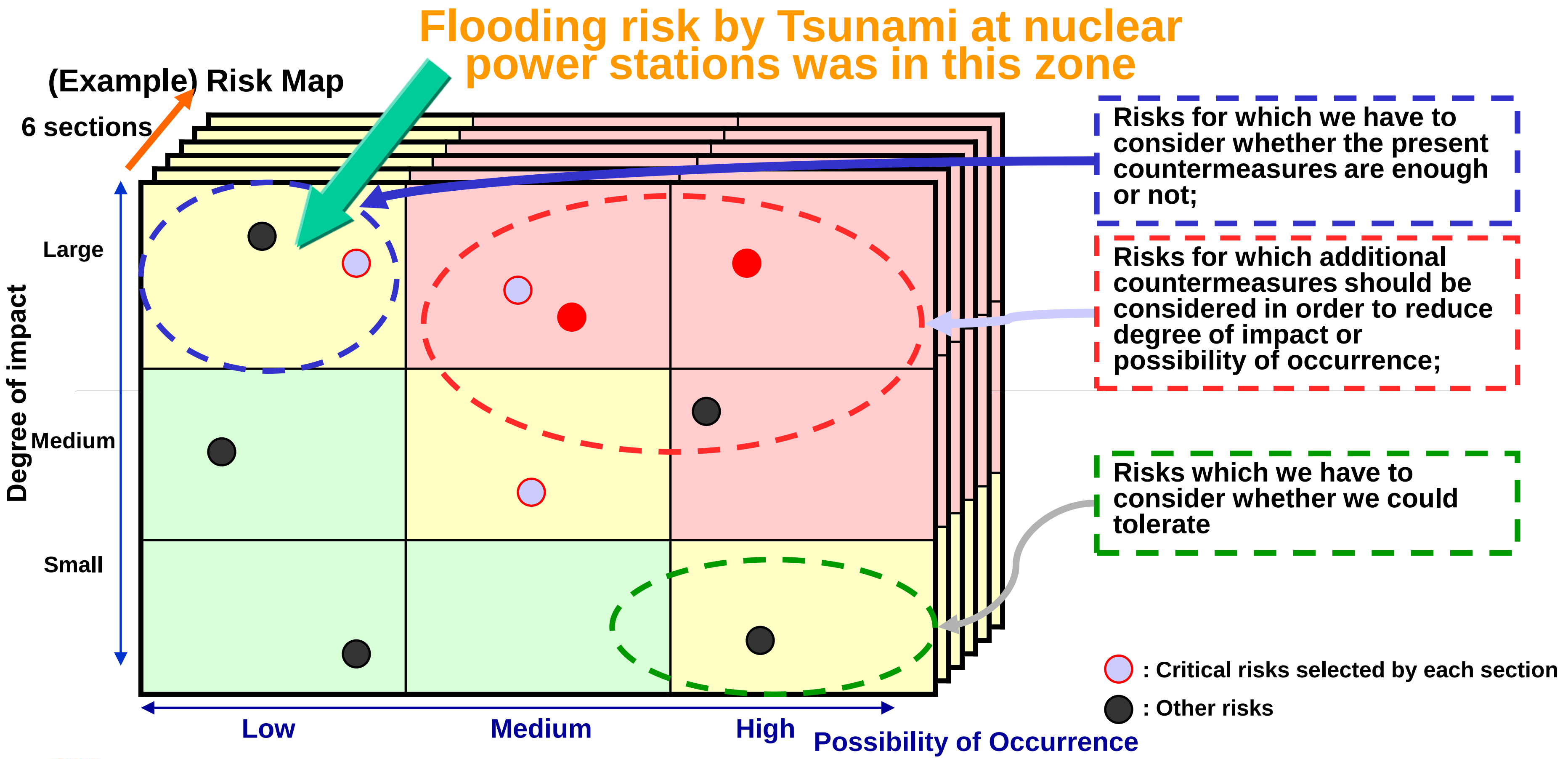
✓ Safety Culture (from INPO special report)

- Cultivating a Questioning Attitude and Challenging Assumptions
- Decision-Making to Reflect a Safety-First Mind-Set
- Clear Recognition of Unique Aspects of the Nuclear Technology
- Learning Organization

✓ External Communication and Relations

Improvement of Risk Management on Nuclear Safety

➢The manner how to discuss the scenario and event with "high consequence and low probability" in the risk management, especially when there is the possibility of the common-mode failures of important safety systems, must be carefully reconsidered.



Challenge towards Nuclear Reform

supervision

Board of Directors

advice

Suggestion

Nuclear Reform Monitoring Committee

【Members】
- Nuclear experts in Japan and the overseas (several)
- Investigation/Verification expert (1 person)
- Chairman Shimokobe

【Chief of Secretariat】
- Professional administrative specialist with a broad overseas network

Operated integrally

Investigation/Verification Project Team

【PT members】
- External Expert (Law, technology)

【 Chief of Secretariat 】
- External practitioner

【Members of Secretariat】
- Internal： Employees other than nuclear related divisions
- External： Lawyers etc.

Discuss/ Report

supervise

Report

Supervise/ Monitor

Execution

Nuclear Reform Special Task Force

【TF chief】President

【Deputy TF chief】 Executive Vice President and Chief Nuclear Officer

【Chief of Secretariat】 General Manager of Nuclear Power and Plant Siting Division

【Members of Secretariat】- Internal： Mid-career and younger employees from the Nuclear Power Division and others (About 10 people)

- External： Experts (Safety Culture, Disaster Prevention, Risk/Crisis Control, Information disclosure, Risk Communication etc.）

Web Site Information

- **TEPCO English website**

http://www.tepco.co.jp/en/nu/fukushima-np/index-e.html

- **TEPCO Internal Investigation Committee Interim Report (Dec. 2nd, 2011)**

http://www.tepco.co.jp/en/press/corp-com/release/11120205-e.html

- **Mid- to Long-Term Road Map Towards Decommissioning of 1F Units 1-4 (Dec. 21st, 2011)**

http://www.tepco.co.jp/en/press/corp-com/release/11122107-e.html

- **NISA (Nuclear and Industrial Safety Agency)**

http://www.nisa.meti.go.jp/english/

- **Government Investigation Committee Interim Report (Dec. 26th, 2011)**

http://icanps.go.jp/eng/interim-report.html

- **INPO—Special Report on Fukushima Daiichi Nuclear Power Station**

http://www.nei.org/resourcesandstats/documentlibrary/safetyandsecurity/reports/special-report-on-the-nuclear-accident-at-the-fukushima-daiichi-nuclear-power-station

- **EPRI—Fukushima Daini Independent Review and Walkdown**

http://my.epri.com/portal/server.pt?Abstract_id=000000000001023422

Thanks for your attention !

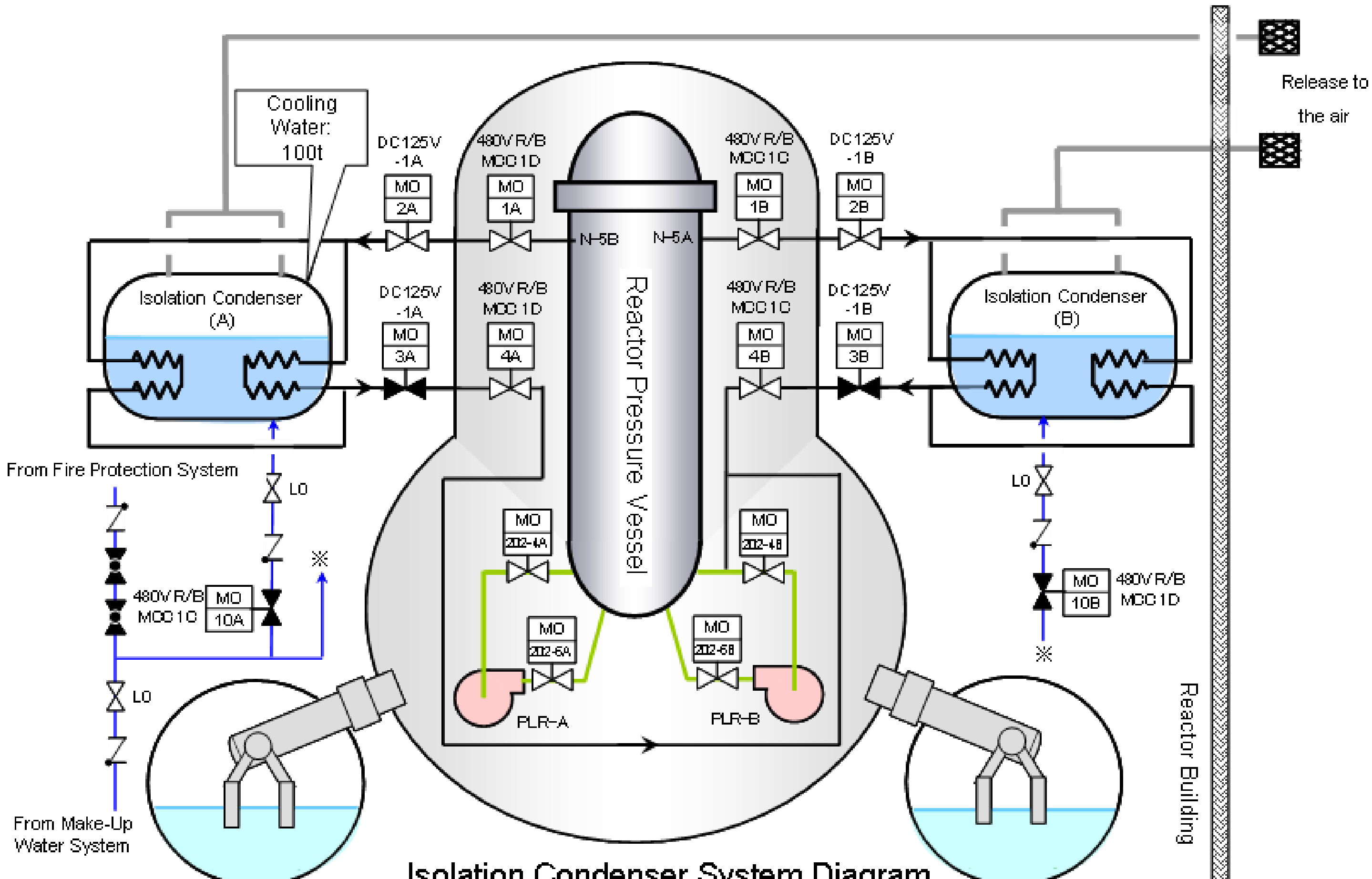
&

Thank you so much for all of your supports you have already provided us and in anticipation of your continuous supports in future !

Reference

Configuration of U1 Isolation Condenser

It is considered that core damage had progressed in a short period of time after the tsunami. Hence, the status of the IC, which is used to cool the reactor in the initial stages after shutdown, might have affected the event progression.

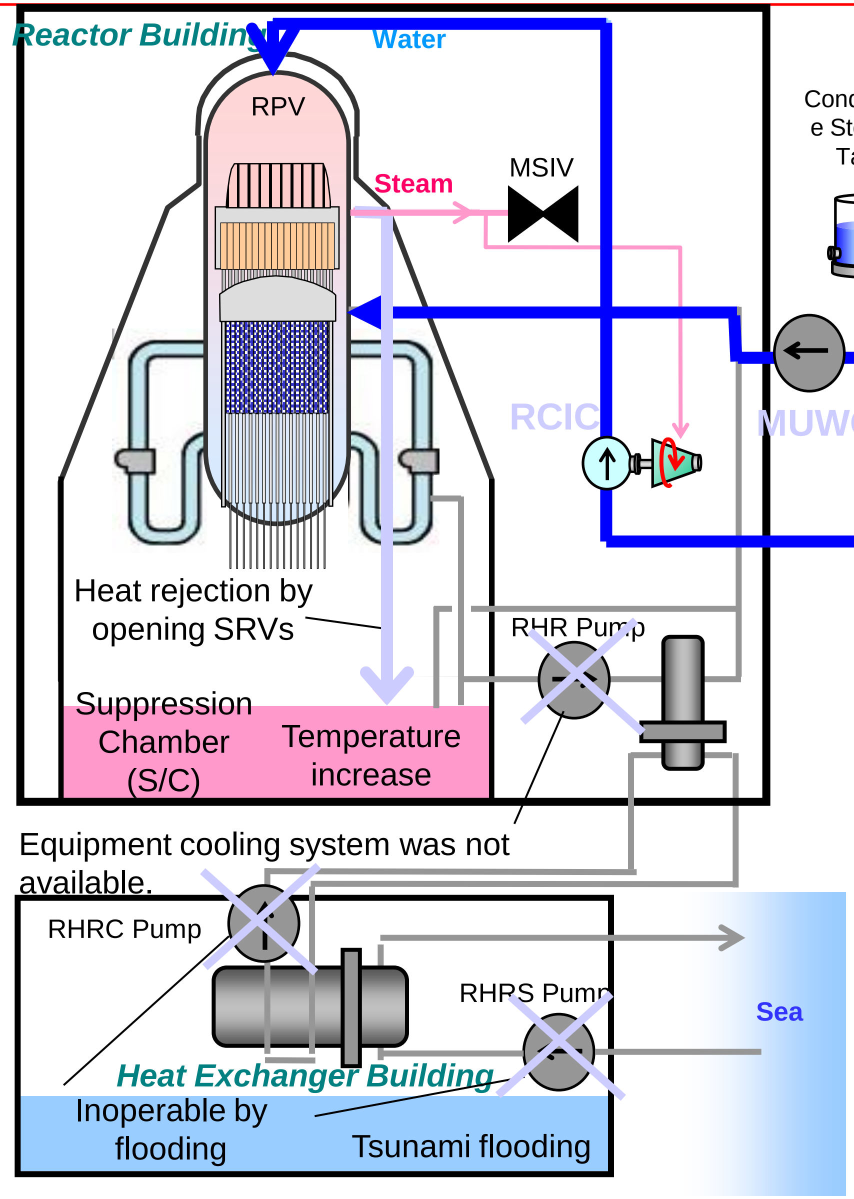


Isolation Condenser System Diagram

2F Recovery Process

Response at Main Control Room and TSC

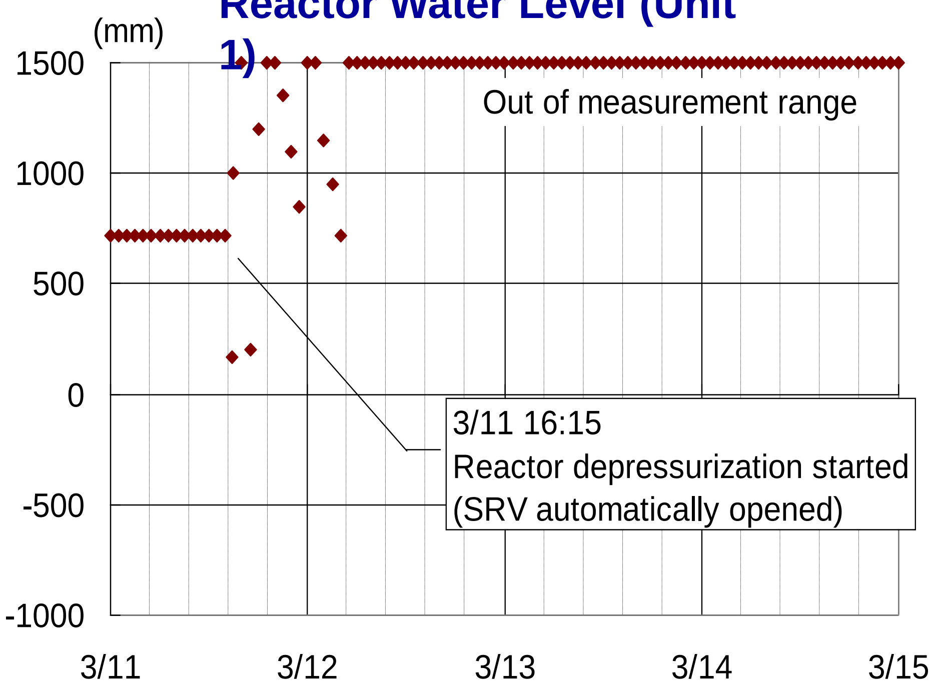
- Operator's initial response
  - MSIVs closed manually, and reactor pressure controlled by SRVs.
  - RCIC actuated manually to maintain reactor water level. RCIC repeated automatic trip due to high water level signal and manual restart.
  - MUWC actuated for alternative water injection measure introduced for Accident Management, as stated in EOP manual for seamless water injection.
  - Reactor depressurized and RCIC stopped due to steam pressure decrease.
  - Water level maintained by MUWC.



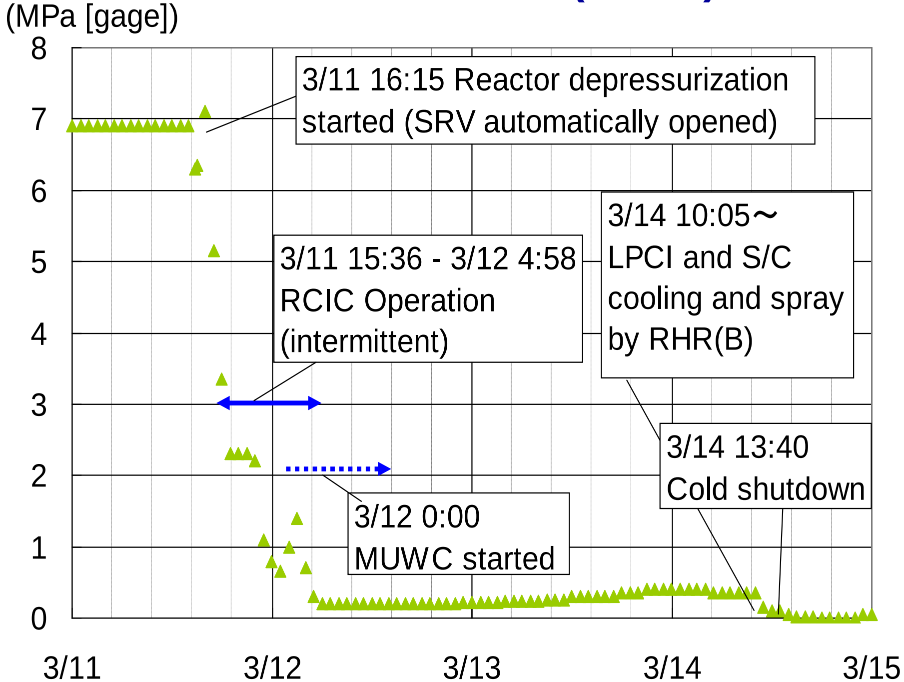
Successful Reactor Cooling during Transient

Securing uninterrupted water injection throughout the depressurization process with RCIC at high pressure condition and MUWC at low pressure condition was a critical factor for successful reactor cooling.

Reactor Water Level (Unit 1)



Reactor Pressure (Unit 1)



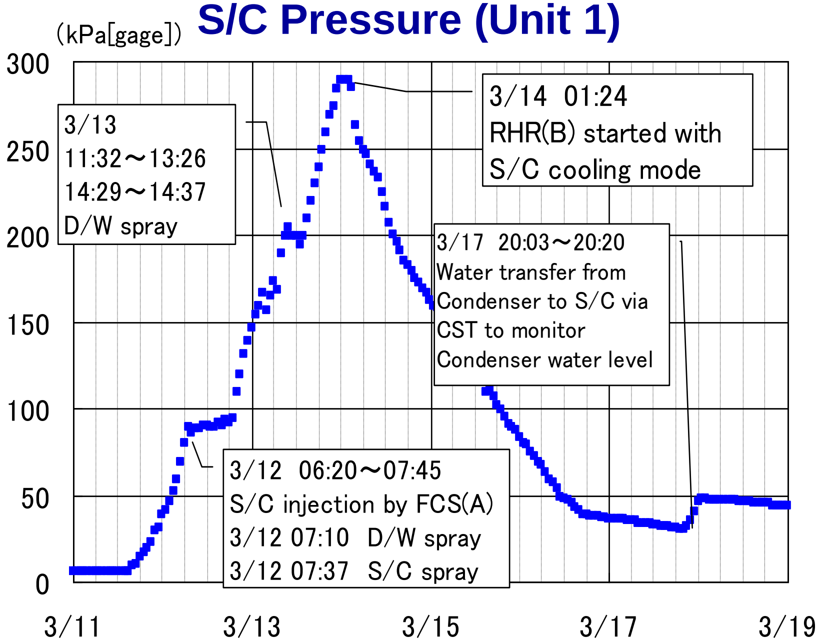
Efforts to Control Temperature and Pressure in PCV

- S/C water temperature reached 100ºC (212F).
  → It eventually increased up to about 130ºC (266F).
- Water injected to S/C through Hydrogen Recombiner cooler discharge line in order to mitigate temperature and pressure increases.
- Alternative injection to reactor using MUWC switched to D/W spray, then S/C spray.
- S/C temperature decreased after restoration of RHR.

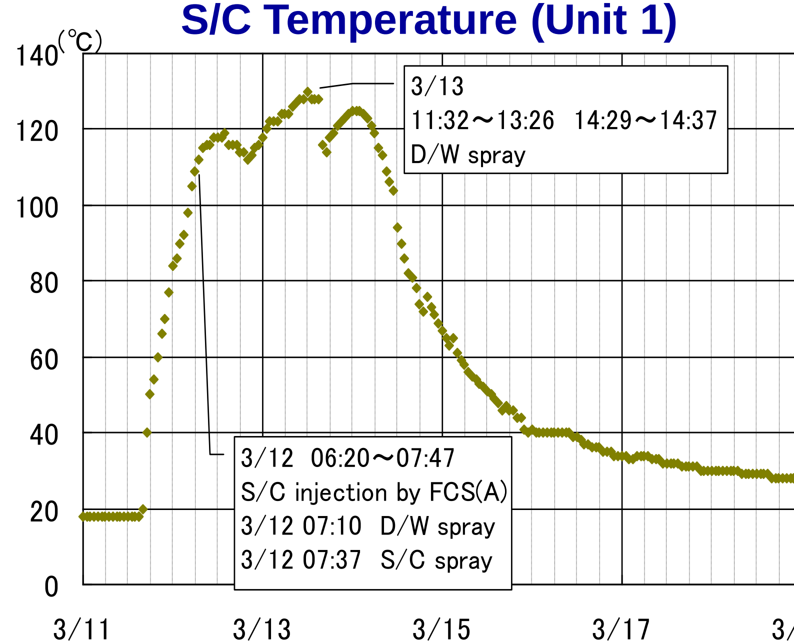
EOP includes an alternative water injection measures employing MUWC .

Flexible approach to cool S/C using Hydrogen Recombiner worked well.

S/C Pressure (Unit 1)



S/C Temperature (Unit 1)



System Status after the Tsunami at 2F

System		Unit 1		Unit 2		Unit 3		Unit 4	
RHR(A) including cooling systems	RHR(A)	×	inoperable due to the loss of power source and cooling system	△	inoperable due to the loss of cooling system	△	inoperable due to the loss of cooling system	△	inoperable due to the loss of cooling system
	RHRC/RCRS(A,C)	×	inoperable due to the submerge of power source and motor	×	inoperable due to the submerge of power source and motor	×	inoperable due to the submerge of power source and motor	×	inoperable due to the submerge of power source and motor
	EECW(A)	×	inoperable due to the submerge of power source and motor	×	inoperable due to the submerge of power source and motor	×	inoperable due to the submerge of power source and motor	×	inoperable due to the submerge of power source and motor
LPCS		×	inoperable due to the loss of power source and cooling system	△	inoperable due to the loss of cooling system	△	inoperable due to the loss of cooling system	△	inoperable due to the loss of cooling system
EDG(A)		×	inoperable due to submerge	△	inoperable due to the loss of cooling system	△	inoperable due to the loss of cooling system	△	inoperable due to the loss of cooling system
RHR(B) including cooling systems	RHR(B)	△	inoperable due to the loss of cooling system	△	inoperable due to the loss of cooling system	○	stand-by	△	inoperable due to the loss of cooling system
	RHRC/RCRS(B,D)	×	inoperable due to the submerge of power source and motor	×	inoperable due to the submerge of power source	○	stand-by	×	inoperable due to the submerge of power source and motor
	EECW(B)	×	inoperable due to the submerge of power source and motor	×	inoperable due to the submerge of power source	○	operation	×	inoperable due to the submerge of power source
RHR(C)		△	inoperable due to the loss of cooling system	△	inoperable due to the loss of cooling system	○	stand-by	△	inoperable due to the loss of cooling system
EDG(B)		×	inoperable due to submerge	△	inoperable due to the loss of cooling system	○	operation	△	inoperable due to the loss of cooling system
RWCU		△	inoperable due to the loss of cooling system	△	inoperable due to the loss of cooling system	△	inoperable due to the loss of cooling system	△	inoperable due to the loss of cooling system
MUWC (alternative water injection)	MUWC(B)	○	stand-by	○	stand-by	○	stand-by	○	stand-by
RCIC		○	stand-by	○	stand-by	○	stand-by	○	stand-by

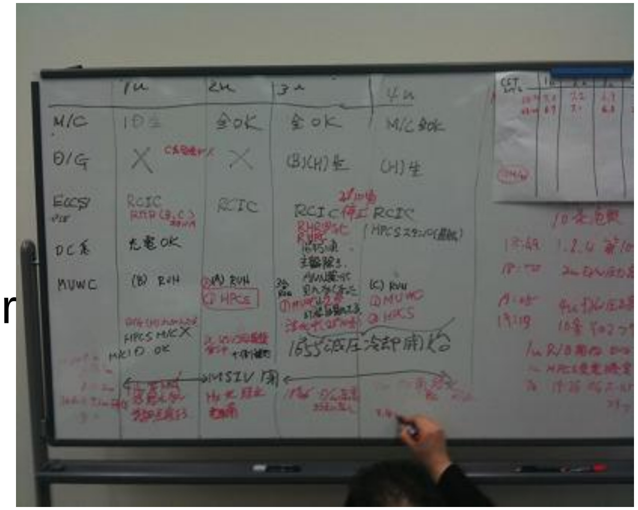
○ ; secure (power, pump and motor all working) △ ; malfunction (inoperable due to factor other than power, pump or motor)

× ; loss of function (power, pump or motor inoperable)

Field Walkdown

In order to establish a well-prioritized restoration strategy, degree of damage and possibility of short-term restoration must be understood through walkdown.

- Challenges in conducting field walkdown
  - Under continuous tsunami alerts, walkdown must be done in the field where a lot of debris, openings and flooding areas existed in the dark.
  - Preparation for emergency evacuation in case of further tsunami and other safety measures for personnel going out to the field.
  - Successful access to the field was 6 hours after the tsunami flooding.
- Field walkdown after the tsunami
  - Plant equipment status checked / component functionality verified.
  - Results were summarized and shared at TSC.
  - TSC set priorities on recovery of RHR (B) cooling systems by replacing motors and supplying power from survived electrical buses and mobile power vehicles through temporary cable.



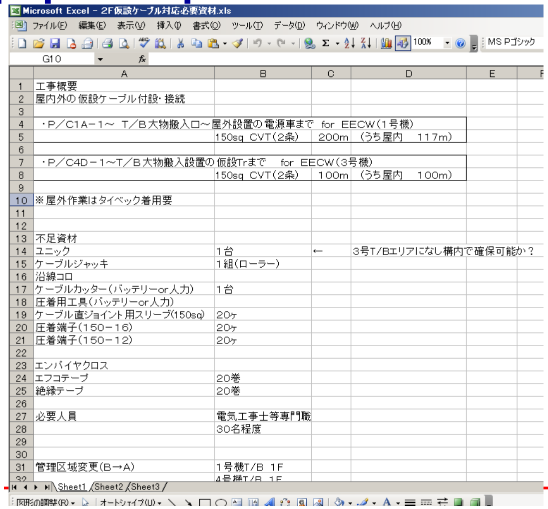
Logistics in Emergency Situation

- Procurement and transportation of Materials and Equipment
  - Emergency procurement of motors, cable, mobile power vehicles, fuel oil and mobile transformers with close cooperation between site TSC and corporate ERC.
  - Rated output of some motors were not the same as that of the original motors.

  →TSC determined to install them based on the evaluation of actual load conditions.
- Difficulties experienced in logistics
  - Motors were transported from Toshiba by a chopper of SDF and from Kashiwazaki Kariwa NPP by trucks.
  - Securing redundant communication measures were critically important when major highway was damaged and public cell phone services were disrupted.

Mobile Power Vehicles

Necessary materials and equipment prioritized and listed



Microsoft Excel - 2F仮設ケーブル対応必要資材.xls

	A	B	C	D	E
1	工事概要				
2	屋内外の仮設ケーブル付設･接続				
3					
4	・P／C1A−1～ T／B大物搬入口～屋外設置の電源車まで for EECW（1号機）				
5		150sq CVT（2条）	200m	（うち屋内 117m）	
6					
7	・P／C4D−1～T／B大物搬入設置の仮設Trまで for EECW（3号機）				
8		150sq CVT（2条）	100m	（うち屋内 100m）	
9					
10	※屋外作業はタイベック着用要				
11					
12					
13	不足資材				
14	ユニック	1台	←	3号T/Bエリアになし構内で確保可能か？	
15	ケーブルジャッキ	1組（ローラー）			
16	沿線コロ				
17	ケーブルカッター（バッテリーor人力）	1台			
18	圧着用工具（バッテリーor人力）				
19	ケーブル直ジョイント用スリーブ(150sq)	20ヶ			
20	圧着端子（150−16）	20ヶ			
21	圧着端子（150−12）	20ヶ			
22					
23	エンパイヤクロス				
24	エフコテープ	20巻			
25	絶縁テープ	20巻			
26					
27	必要人員	電気工事士等専門職			
28		30名程度			
29					
30					
31	管理区域変更（B→A）	1号機T/B 1F			
32		4号機T/B 1F			

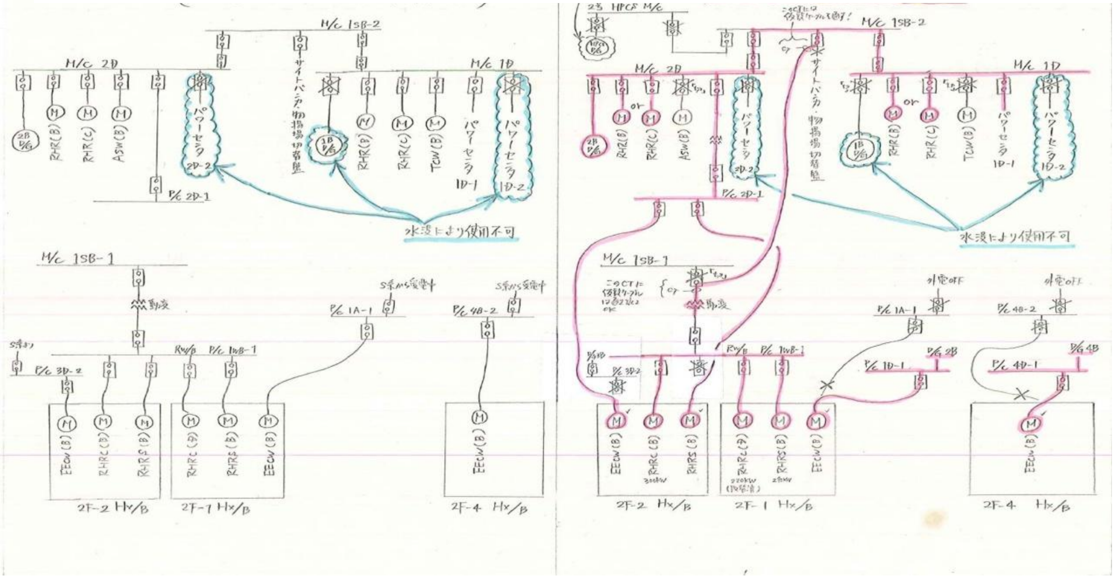
Fuel oil delivery to the site

Emergency Restoration Efforts in the Field

- Pumps of RHR cooling systems (RHRC, RHRS, EECW) were inspected.
- Motors were replaced for pumps in RHRC and EECW.
- In order to restore the inundated electrical buses, temporary cable and high voltage mobile power vehicles were deployed.
- Temporary cable was laid from survived power cubicles in Rad-Waste Building and Unit 3 Heat Exchanger Building.

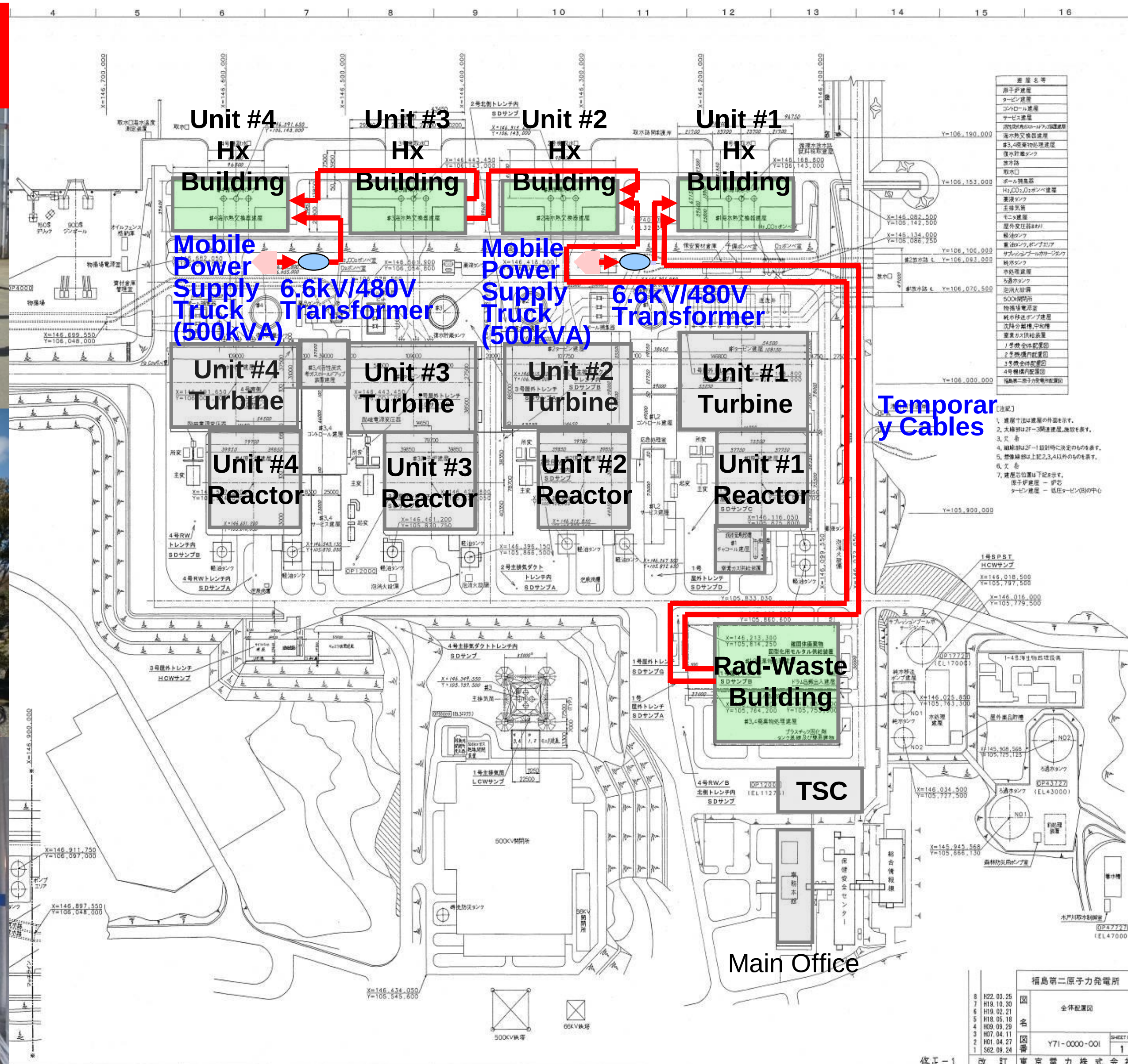
Motor replacement

Drawing made at TSC for temporary cable laying



Temporary Power Supply and Motor Replacement at 2F

About 9 km of temporary cables were laid and motors were replaced.



System Status after Emergency Restoration at 2F

System		Unit 1		Unit 2		Unit 3		Unit 4	
RHR(A) including cooling systems	RHR(A)	×	inoperable due to loss of power source and cooling system	△	inoperable due to loss of cooling system	△	inoperable due to loss of cooling system	△	inoperable due to loss of cooling system
	RHRC/RCRS(A,C)	×	inoperable due to submerge of power source and motor	×	inoperable due to submerge of power source and motor	×	inoperable due to submerge of power source and motor	×	inoperable due to submerge of power source and motor
	EECW(A)	×	inoperable due to submerge of power source and motor	×	inoperable due to submerge of power source and motor	×	inoperable due to submerge of power source and motor	×	inoperable due to submerge of power source and motor
LPCS		×	inoperable due to loss of power source and cooling system	△	inoperable due to loss of cooling system	△	inoperable due to loss of cooling system	△	inoperable due to loss of cooling system
EDG(A)		×	inoperable due to submerge	△	inoperable due to loss of cooling system	△	inoperable due to loss of cooling system	△	inoperable due to loss of cooling system
RHR(B) including cooling systems	RHR(B)	○	operation	○	operation	○	operation	○	operation
	RHRC/RCRS(B,D)	○	operation	○	operation	○	operation	○	operation
	EECW(B)	○	operation	○	operation	○	operation	○	operation
RHR(C)		○	stand-by	○	stand-by	○	stand-by	○	stand-by
EDG(B)		△	operable using tie-line from unit #2	○	stand-by	○	stand-by	○	stand-by
RWCU		△	inoperable due to the loss of purge line	△	inoperable due to the loss of purge line	△	inoperable due to the loss of purge line	△	inoperable due to the loss of purge line
MUWC (alternative water injection)	MUWC(B)	○	stand-by	○	stand-by	○	stand-by	○	operation
RCIC		×	inoperable for loss of core pressure	×	inoperable for loss of core pressure	×	inoperable for loss of core pressure	×	inoperable for loss of core pressure

○ ; secure (power, pump and motor all working) △ ; malfunction (inoperable due to factor other than power, pump or motor)

× ; loss of function (power, pump or motor inoperable)

2F Key Success Factors

Organization and Management Features

- Accident mitigation by applying EOP and AMG
- Prioritized restoration strategy based on Field Walkdown
- Prompt restoration with success of emergency procurement for materials and equipment
- Logistics for long term emergency response
- Organizational integrity: Leadership, Communication, Accountability, Professionalism

Design/Engineering Features

- Availability of most of M/C, P/C and Battery
- Availability of off-site power